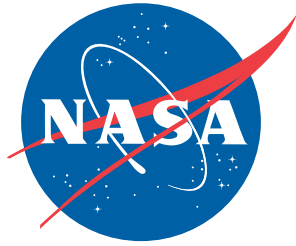


NASA/TM-2011-217085/Volume II
NESC-RP-09-00598



Flight Simulation Model Exchange

Appendices

*Daniel G. Murri/NESC
Langley Research Center, Hampton, Virginia*

*E. Bruce Jackson
Langley Research Center, Hampton, Virginia*

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

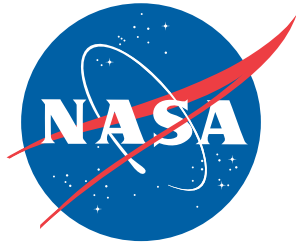
- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA STI Help Desk at 443-757-5803
- Phone the NASA STI Help Desk at 443-757-5802
- Write to:
NASA STI Help Desk
NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320

NASA/TM-2011-217085/Volume II
NESC-RP-09-00598



Flight Simulation Model Exchange

Appendices

*Daniel G. Murri/NESC
Langley Research Center, Hampton, Virginia*

*E. Bruce Jackson
Langley Research Center, Hampton, Virginia*

National Aeronautics and
Space Administration


Langley Research Center
Hampton, Virginia 23681-2199

April 2011

The use of trademarks or names of manufacturers in the report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

| | | | |
|---|---|---|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00589 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 1 of 343 |

Flight Simulation Model Exchange Volume II

NRB Review Date: February 17, 2011



| | | | |
|---|---|---|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 2 of 343 |

Table of Contents

Volume II: Appendices

| | |
|---|-----|
| Appendix A. NESC Flight Simulation Model Exchange Assessment Report from Johnson Space Center | 3 |
| Appendix B. American National Standard: Flight Dynamics Model Exchange Standard (draft BSR/AIAA S-119-201x) | 66 |
| Appendix C. XML Document Type Definition file for S-119 markup: DAVEfunc.dtd..... | 183 |
| Appendix D. Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML) Reference Manual..... | 201 |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 3 of 343 |

Appendix A. NESC Flight Simulation Model Exchange Assessment Report from Johnson Space Center



National Aeronautics and
Space Administration

NASA/ODIN

NESC Flight Simulation Model Exchange Assessment

October 21, 2010

Matthew V. Jessick
LZ Technology

John Penn
L-3 Communications

David Hasan
L-3 Communications

Edwin Z. (Zack) Crues
NASA Johnson Space Center



| | | | |
|---|---|---|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 4 of 343 |

Table of Contents

| | |
|--|----|
| Executive Summary | 4 |
| Acronyms | 6 |
| 1.0 INTRODUCTION | 7 |
| 2.0 SCOPE | 7 |
| 3.0 METHODS..... | 7 |
| 4.0 SOFTWARE INTEGRATION..... | 8 |
| 4.1 Integration of Two Provided DAVE-ML Interpreters with Trick and JEOD2..... | 8 |
| 4.1.1 Lessons Learned | 15 |
| 4.2 Simulation Data Mapping, and Testing | 15 |
| 4.3 TDM_Map: Trick to DAVE-ML Variable Name Mapping..... | 15 |
| 4.3.1 Lessons Learned | 17 |
| 4.4 Autocoding DAVE-ML to C via XSLT | 19 |
| 4.4.1 Feasibility of Transforming a Legal DAVE-ML Model into Executable “C” Code. | 19 |
| 4.4.2 Design - Mapping DAVE-ML Elements to “C” Code..... | 20 |
| 4.4.3 Lessons Learned | 24 |
| 4.5 HL-20 Auto-Landing Simulation | 33 |
| 5.0 EXECUTION TIME STUDY OF DAVE-ML INTERPRETERS | 37 |
| 5.1 Trick Job Timing System | 37 |
| 5.2 Test Computer and Operating System Specifications..... | 37 |
| 5.3 Compiler and Compilation Flags..... | 38 |
| 5.4 Miscellaneous Settings..... | 38 |
| 5.5 Weaknesses of the Test Method | 38 |
| 5.6 Timing Results..... | 38 |
| 5.7 Interpretation of the Results | 40 |
| 6.0 NON-AERODYNAMICS MODELS IMPLEMENTED IN DAVE-ML | 40 |
| 6.1 HL-20 RCS Algorithm..... | 40 |
| 6.1.1 Ad hoc “Macro” Substitutions via XSLT | 41 |
| 6.1.2 Test Method..... | 45 |
| 6.1.3 Results..... | 45 |
| 6.1.4 Lessons Learned | 48 |
| 6.2 Pneumatic Tire Data Compression Model | 49 |
| 6.2.1 Ad hoc “Macro” Substitutions via Script..... | 51 |
| 6.2.2 Lessons Learned | 52 |

| | | | |
|---|---|---|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 5 of 343 |


| | |
|---|----|
| 7.0 DAVE-ML SPECIFICATION COMMENTS/SUGGESTIONS..... | 53 |
| 7.1 Uncertainty Element | 53 |
| 7.2 GriddedTableDef Element | 55 |
| 7.3 CheckData Element | 55 |
| 8.0 CONCLUSIONS | 56 |
| 9.0 FUTURE WORK..... | 56 |
| 10.0 BIBLIOGRAPHY | 58 |
| APPENDIX A Draft DAVE-ML Uncertainty Reference..... | 59 |

Table of Figures

| | |
|---|----|
| Figure 1. Layered Software Structure..... | 9 |
| Figure 2. Summary UML class diagram. | 11 |
| Figure 3. Generic DAVE-ML model integration with sim | 12 |
| Figure 4. HL-20 aerodynamic model integration with sim. | 12 |
| Figure 5 DaveMLModel Interface in UML..... | 13 |
| Figure 6. TDM_Map Software UML Class Diagram | 17 |
| Figure 7. TDM_Map Software UML Sequence Diagram..... | 18 |
| Figure 8. DAVEML Elements and Dependencies that are related to Code Generation | 19 |
| Figure 9. UML Diagram For MathML $$ Elements | 21 |
| Figure 10. HL-20 Trick Sim, Pitch Pulse, Angle of Attack Trace..... | 34 |
| Figure 11. TM 107580 Pitch Pulse, Angle of Attack Trace..... | 34 |
| Figure 12. HL-20 Auto-Landing Trajectory, Overhead Map..... | 35 |
| Figure 13. HL-20 Auto-Landing Trajectory, Angle of Attack (AoA) and Mach Profiles | 36 |
| Figure 14. CPU Time per Call, HL-20 Aero Model..... | 39 |
| Figure 15. HL-20 RCS Algorithm of Powell(18)..... | 41 |
| Figure 16. DAVE-ML HL-20 RCS Algorithm Test Results: Angle of Attack..... | 46 |
| Figure 17. DAVE-ML HL-20 RCS Algorithm Test Results: Roll Angle..... | 47 |
| Figure 18. DAVE-ML HL-20 RCS Algorithm Test Results: Body Rates | 48 |
| Figure 19. Tire Data Compression Model Set..... | 49 |
| Figure 20. Tire Data Compression Model Example Output..... | 51 |

Table of Tables

| | |
|---|----|
| Table 1 Generic Interpreter Interface Methods | 14 |
| Table 2. Touchdown Conditions Compared For The Four HL-20 Aero Model Versions | 36 |
| Table 3. CPU Time per Call Summary, HL-20 Aero Model | 39 |
| Table 4. HL-20 RCS Thruster Model..... | 45 |
| Table 5. HL-20 entry Rigid Body Mass Model..... | 45 |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 6 of 343 |

Executive Summary


This report summarizes an investigation of the DAVE-ML markup language, performed at Johnson Space Center (JSC) during the 2010 fiscal year. The work focused on several areas: (1) Integration of DAVE-ML software with the JSC Trick simulation framework, (2) Analysis of DAVE-ML interpreter performance, (3) Investigation of some non-aerodynamic DAVE-ML models, and (4) Analysis of the S-119 and DAVE-ML XML draft specifications.

Software Integration. Our effort to integrate DAVE-ML into JSC simulation software involved two activities: integration and code generation. The integration activity focused on integrating the two available DAVE-ML interpreter systems (Janus and LaSRS++/DaveMLTranslator) into Trick. The code generation activity involved the development of an XML-to-C/C++ code generator to create compilable code from a DAVE-ML model. For both activities (integration and code generation), we focused primarily on an HL-20 lifting body simulation, incorporating the HL-20 DAVE-ML aerodynamic model with the Trick simulation framework and a JSC dynamics package (JEOD) to provide a planet model, coordinate systems, vehicle dynamics and a vehicle trajectory. We implemented a single "generic" software model that integrated our Trick-based simulations with either the Janus or the LaSRS++ DAVE-ML interpreters. Details of this generic design are provided in the report. We also implemented an XSLT-based XML-to-C/C++ code generator that allows the DAVE-ML model algorithms to be executed directly rather than interpreted in the Janus or LaSRS++ DAVE-ML "virtual machines". We found this generated code useful as a baseline against which to compare the runtime performance of the interpreted approach. It could also be used to compare against a hand coded translation of a DAVE-ML transferred algorithm during development.

Execution Time Study of DAVE-ML Interpreters. Our performance analysis of DAVE-ML models involved the investigation of a Trick-based HL20 auto-landing simulation integrated with (1) the Janus DAVE-ML interpreters, (2) the LaSRS++ DAVE-ML interpreter, (3) the C code auto-coded from our XML-to-C/C++ code generator, and (4) some pre-existing hand-coded HL-20 source code. In all four cases, the simulations generated the same trajectory. We found that interpreted DAVE-ML was of comparable speed to auto-generated compiled C code and hand tuned code for the limited testing we performed. Detailed results are available in the report, including some of the weaknesses of the method we used for performance analysis.


Non-Aerodynamics Models Implemented in DAVE-ML. In addition to our work with the HL-20 aerodynamics model, we looked at two non-aerodynamic DAVE-ML models: (1) An HL-20 reaction control system (RCS) algorithm, and (2) A pneumatic tire force model. Our investigation of the RCS algorithm, in particular our successful representation of it in DAVE-ML and subsequent execution of the model using the Janus and LaSRS++ interpreters and our XML-to-C/C++ code generator, offers some evidence that models beyond the aerodynamics niche can indeed be represented through the current DAVE-ML specification. In particular, dynamic models with saved states can be created in DAVE-ML 2.0 without direct support in the specification, by the caller providing work space for the states. This worked reasonably well when aided by a convenient method of hooking together corresponding simulation and internal DAVE-ML interpreter variables. Our investigation of a pneumatic tire data compression model showed that the self-documenting properties of DAVE-ML can be used to record provenance, modification, and accuracy data for static data sets; sophisticated models can be created entirely in MathML without recourse to table look-ups; and that models can be created in a hierarchy where the outputs from one are then fed into the next in DAVE-ML 2.0, even though this feature is not supported directly in the specification. Further details are available in the body of report.

DAVE-ML Specification Comments/Suggestions. In the course of our investigations, we collected some observations about the DAVE-ML specification, in particular the XML DTD. These observations are primarily the result of (1) our code generation work and (2) a detailed look we took into the DAVE-ML uncertainty element. Generally we found that in a few places the DAVE-ML DTD is insufficiently precise to support automatic code generation (e.g., certain XML element attributes are optional leading to the possibility that a DAVE-ML compliant XML model might not allow code generation without some manual intervention). We also found that the

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 7 of 343 |


documentation of the uncertainty element in the Reference Manual could be improved, and we drafted a proposed replacement for the relevant section of the Reference Manual to fix some (but not all) of the weaknesses we found. Our detailed observations are available in the body of the report.

Conclusions and Suggestions for Future work. We suggested several clarifications and changes to the DAVE-ML specification that are described in more detail later in this report, and summarized in the conclusions section. We feel these changes would improve the rigor and clarity of the specification, making it easier to develop interpreters and code generators for DAVE-ML, and helping to transfer models without ambiguity. The feasibility of an XSLT based DAVE-ML to “C” code generation capability was demonstrated during this assessment. Although incomplete, the system prototyped during this project is useful now and shows considerable potential for future expansion. The utility of the DAVE-ML specification for use by non-aerodynamics models was shown by two test cases, that also investigated hierarchical models, a pseudo-dynamic model with saved states implemented via caller provided memory storage, and demonstrated two ways to use “macros” (essentially) to ease MathML authoring for complex algorithms. We suggested several areas where future work would be useful. These include further exploration of the S-119 and DAVE-ML specifications, continued development of the XSLT code generator toward an operational capability, and testing of the DAVE-ML <uncertainty> element by exercising it to specify dispersion test cases for the Trick Monte-Carlo capability.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 8 of 343 |

Acronyms

| | |
|---------|--|
| AIAA | American Institute of Aeronautics and Astronautics |
| API | Application Programming Interface |
| DAVE-ML | Dynamic Aerospace Vehicle Exchange Markup Language. |
| DSTO | Defense Science and Technology Organization (Australian Dept. of Defense) |
| DTD | Document Type Definition. |
| FSME | Flight Simulation Model Exchange program of the NESC |
| GNC | Guidance, Navigation and Control |
| HAC | Heading Alignment Cylinder (or Circle) |
| JEOD2 | JSC Engineering Orbital Dynamics model set, version 2 |
| JSC | NASA Johnson Space Center |
| LaRC | NASA Langley Research Center |
| LaSRS++ | Langley Standard Real-Time Simulation in C++ |
| MathML | Mathematics Markup Language. |
| NASA | National Aeronautics and Space Administration |
| NESC | NASA Engineering Safety Center |
| RCS | Reaction Control System |
| S-119 | Draft Specification: "Flight Dynamics Model Exchange Standard," BSR/AIAA S-119-200X |
| Trick | The Trick Simulation Environment |
| UML | Unified Modeling Language |
| XML | Extensible Markup Language |
| XSLT | Extensible Stylesheet Language Transformations |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 9 of 343 |

1.0 INTRODUCTION

The goals of this project were to support the NASA Engineering Safety Center (NESC) in their efforts to study the American Institute of Aeronautics and Astronautics (AIAA) draft specification S-119 Flight Simulation Model Exchange (FSME). The work at NASA Johnson Space Center (JSC) was part of a multi-center effort to gain experience in integrating Dynamic Aerospace Vehicle Exchange - Markup Language (DAVE-ML) models into the local simulation systems of each center in order to more efficiently transfer simulation models.

2.0 SCOPE

The major tasks were to:

- Review FSME project documents
- Integrate DAVE-ML models into the local (in this case, NASA/JSC) simulation construction flow
- Demonstrate the integration by using the HL20_aero.dml DAVE-ML file as the basis of an HL-20 landing simulation
- Evaluate the S-119(1) and DAVE-ML(2) draft specifications for their purpose
- Provide feedback on the specifications
- Make a recommendation with the other participating centers for the draft specification.


3.0 METHODS

Our basic strategy for integration of DAVE-ML into JSC simulation construction flow was to integrate use of simulation models, expressed in DAVE-ML format XML files, directly into common JSC simulation construction tool sets via example DAVE-ML interpreters. These included the Trick Simulation Environment and the JSC Engineering Orbital Dynamics (JEOD) model set. The two available DAVE-ML interpreter systems were DaveMITranslator(3) (NASA/LARC) and Janus(4) (DSTO).

As a second method of integration, we investigated the feasibility of generating C source code from DAVE-ML file algorithms via XSLT(5)(6) (Extensible Markup Language Transformations). Given the ubiquity of XSLT tools, if found to be feasible, this seemed like a widely applicable method of either directly integrating DAVE-ML models, or at least greatly easing the task of converting models from DAVE-ML to C.

An alternative to this strategy would have been to build tools to convert DAVE-ML file models to local (Trick format) input files and code. One interesting lack in the Trick Simulation Environment, however, is a single preferred method of performing a table look up from data. This is typically left to the model builder. Given the preeminence of such structures in DAVE-ML and without such a baseline code module to target converted input files toward, we felt our time during this assessment was better spent pushing the capabilities of the two provided DAVE-ML interpreter systems to their limits, and also to pursue code generation as better fitting into the usual Trick usage patterns. (Trick simulations typically contain a strong element of code generation).

Evaluation of the S-119 and DAVE-ML specifications ended up being concentrated on the DAVE-ML specification, through an extensive review and suggested re-drafting of the <uncertainty> element, and DAVE-ML Document Type Definition (DTD) issues that cropped up during the XSLT based code generation work.

| | | | |
|---|---|--|-----------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 10 of 343 |

4.0 SOFTWARE INTEGRATION

4.1 Integration of Two Provided DAVE-ML Interpreters with Trick and JEOD2

Two existing DAVE-ML Interpreters provided through the FSME program by the DSTO and NASA/LARC were integrated into the Trick Simulation Environment (Trick(7)) and the JSC Engineering Orbital Dynamics (JEOD version 2 (8)) model package in object oriented fashion.

These two toolsets are in widespread use at NASA/JSC and elsewhere for real-time simulation of vehicles and robotics. One of the major results of the JSC participation in the FSME program is the development of a framework to integrate DAVE-ML capability into these common simulation development toolsets via the DAVE-ML interpreters or a new code generation capability (described later).


The new DAVE-ML capability was exercised primarily through construction of a Trick/JEOD2 based HL-20 auto-landing simulation as specified in the FSME program. This new simulation featured runtime interpretation of a DAVE-ML aerodynamics model simulating the flight of the HL-20 as a single rigid body from Mach 4 to touchdown. The HL-20 simulation is able to run in real-time or non-real-time modes, unpiloted, and lands under the control of an auto-coded auto-landing guidance, navigation and control (GN&C) algorithm provided by NASA/LARC.

Additional miscellaneous simulations were constructed using the same structure to exercise other DAVE-ML models for various purposes during the study and will be described later.

Figure 1 shows the layered hierarchy of simulation software modules used to construct the HL-20 auto-landing simulation, which was developed during this program. Each layer uses the capabilities provided by the layer below. The simulation is shown divided into four major layers, and data files:

- Simulation Environment
- User Models
- DAVE-ML Interpreters
- 3rd Party Libraries
- plus the Data Files.

These five areas are separated by dashed lines in Figure 1. The solid lines in the figure indicate software module interactions. The arrows show data flow for DAVE-ML file interpretation during runtime and also code generation of MatLab™ models to code.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 11 of 343 |

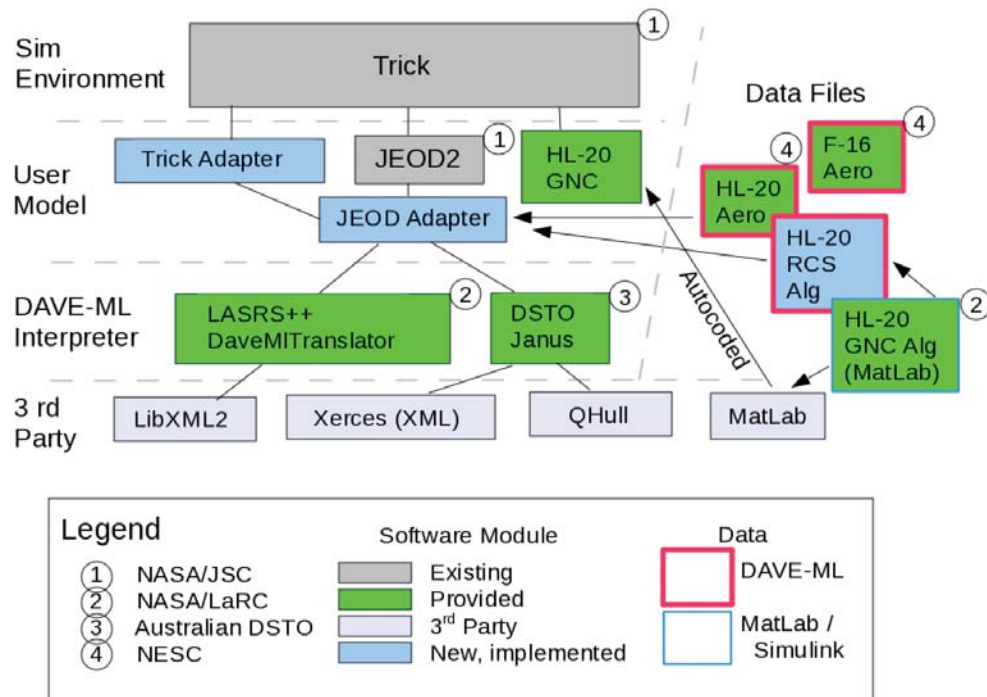



Figure 1. Layered Software Structure

The Trick Simulation Environment served as the base framework for the simulation, providing simulation executive functions, model organization, and code generation, as well as real-time capability and input, output, monitoring, and plotting facilities.

The JEOD version 2 model package provided the bulk of the simulation models. These included time management, planet models and ephemerides, environment, coordinate systems, vehicle dynamics and trajectory integration. The JEOD general models were customized for this application using the Trick code generation and input systems. JEOD provides the DefaultAero class as a hook for further specialization by the user. DefaultAero was used as the base class from which the JEOD adapter modules were derived to hook DAVE-ML aero models into the simulation. Two software adapter objects were constructed to integrate the two provided DAVE-ML interpreters into the simulation structure in an object oriented fashion for the purposes of this investigation.

The two DAVE-ML interpreters formed the third layer of the simulation:

- Janus(4) provided by the Australian Defence Science and Technology Organization (DSTO), and
- DaveMITranslator(3), part of the LASRS++ simulation, provided by the NASA/Langley Research Center.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 12 of 343 |

The major third party libraries forming the bottom layer of the simulation are also indicated in the diagram. These included:


| | |
|------------|--|
| LibXML2(9) | A cross-platform XML library used by DaveMITranslator (In wide use as the XML provider for the Linux GNOME desktop) |
| Xerces(10) | A cross-platform XML library used by Janus (In wide use as the XML provider for the Apache web server) |
| Qhull(11) | A Convex Hull library used by Janus for ungridded table look ups. (In wide use by: MatLab, GNU Octave, Mathematica, Google, etc.) |

Additionally, MatLab™/ Simulink™/ Real Time Workshop™, a visual modeling system with code generation capability, was used to view and generate C code for the HL-20 Auto-landing guidance, navigation and controls (GNC) algorithms from Simulink™ files provided by NASA/LARC.

This structure allows DAVE-ML models to be loaded as XML files into a Trick/JEOD based simulation during initialization, either as JEOD aerodynamic models or as general models; and interpreted during runtime via either of the two supported DAVE-ML interpreters. The interpreter module to be used may be selected for each model during initialization via Trick input processing.

The circled numbers in the diagram indicate the source of existing and provided modules and files per the Legend. The blue colored "Implemented" items were newly constructed during this program. These include the various adapter modules used to integrate DAVE-ML models into Trick and JEOD, the HL-20 reaction control system (RCS) algorithm implemented in DAVE-ML, and the "glue code" required to integrate the autocoded GN&C algorithm into the simulation.

A summary UML(12) (Unified Modeling Language) class diagram showing the details of the software integration is shown in Figure 2.

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | Page #: 13 of 343 |

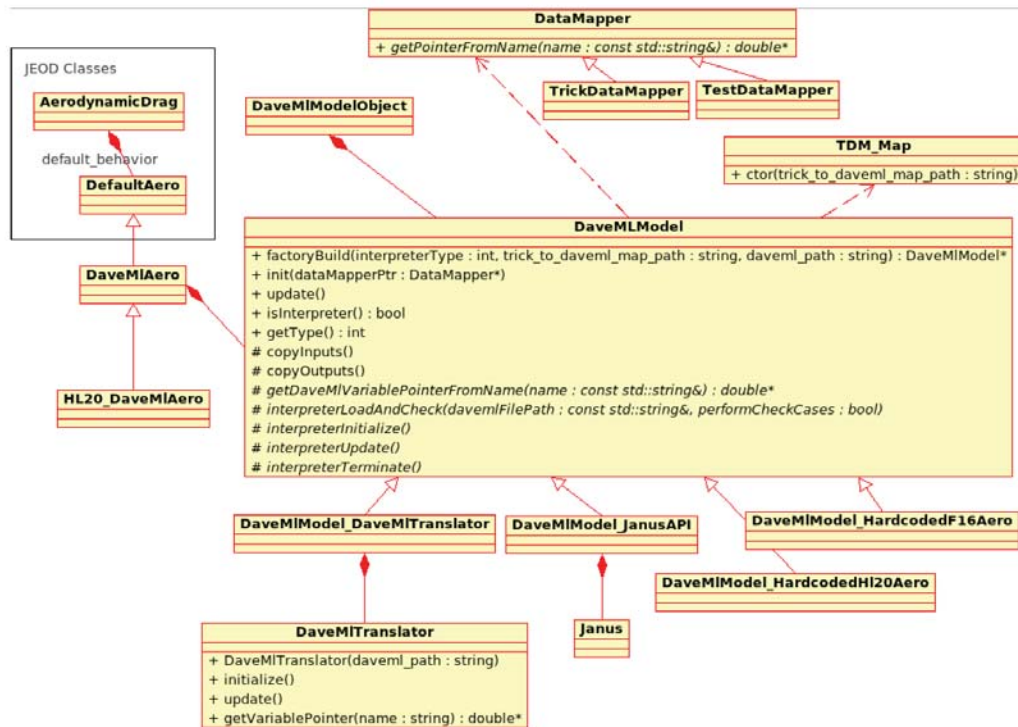



Figure 2. Summary UML class diagram.

This implementation uses several object oriented software "Design Patterns"(13):

- The "Strategy" design pattern is used to select amongst similar algorithms that all provide a consistent interface to the using software modules via C++ inheritance.
- The "Factory" design pattern is used to simplify construction of objects of the selected type.
- The "Adapter" design pattern is used to adapt the differing interfaces of DaveMLTranslator and Janus into a single interface capable of operating both embedded interpreters at the minimal level required of the simulation.
- The DaveMLTranslator base class uses the "Template Method" pattern to access the underlying interpreter APIs in a generic way.

Current DAVE-ML version 2.0 models can be summarized as multi-input multi-output functions with no internal states. To use the models, the values of simulation input variables (e.g.: angle of attack) must be passed to the corresponding variables within the DAVE-ML model. The values of the output variables of the DAVE-ML model

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 14 of 343 |

must then be passed back to corresponding output variables owned by the simulation. This basic structure is shown in Figure 3, and a specific example for the HL-20 aero model in Figure 4.

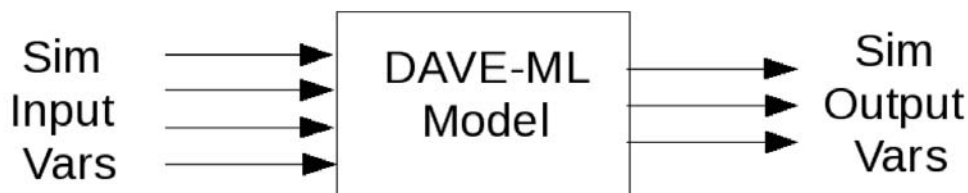


Figure 3. Generic DAVE-ML model integration with sim

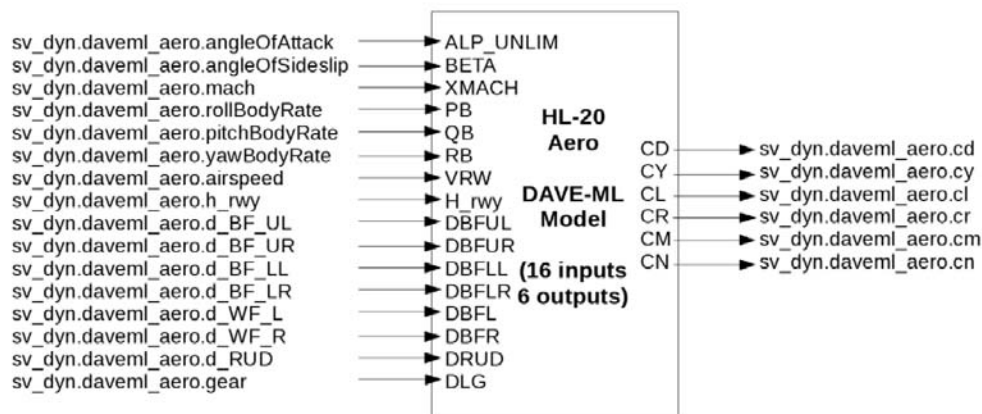


Figure 4. HL-20 aerodynamic model integration with sim.


Two capabilities of the implemented software are potentially of general interest. These include the:

- TDM_Map class, providing a way to read an XML file specifying a mapping between the names of sim variables and corresponding DAVE-ML model variable names.
- DataMapper class and sub-classes. This system provides a general interface to obtain a pointer to a simulation variable. When integrating with Trick, the TrickDataMapper subclass uses the Trick API to provide this service. The TestDataMapper subclass simply allows unit test code to enter {name,pointer} pairs to hook the model up to test code without requiring the Trick systems.

Both of these systems could be used or extended for use in other simulation environments. These systems are discussed in individual sections further below.

The DaveMlModel class serves to adapt the differing application programming interfaces (APIs) of DaveMlTranslator and Janus to a single generalized interface. (Note: In doing so, the additional flexibility of Janus allowing calculation of less than the full set of outputs was suppressed.)

Figure 5 shows the DaveMlModel interface in UML. Methods shown with a “+” are public, those with “#” are private, and those in italics are pure abstract methods that are required to be implemented by all subclasses.

| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 15 of 343 |

| DaveMLModel |
|---|
| <pre> + factoryBuild(interpreterType : int, trick_to_daveml_map_path : string, daveml_path : string) : DaveMLModel* + init(dataMapperPtr : DataMapper*) + update() + isInterpreter() : bool + getType() : int # copyInputs() # copyOutputs() # getDaveMLVariablePointerFromName(name : const std::string&) : double* # interpreterLoadAndCheck(davemlFilePath : const std::string&, performCheckCases : bool) # interpreterInitialize() # interpreterUpdate() # interpreterTerminate() </pre> |

Figure 5 DaveMLModel Interface in UML.

Once during initialization processing, the static member function `factoryBuild` is called to create the selected type of DAVE-ML interpreter - `DaveMLTranslator` or `Janus` - and to specify the file names of the DAVE-ML file defining the model and the `TDM_Map` XML file specifying the correspondance between simulation and internal DAVE-ML model variable names. The `init()` member function is then called once. (Optionally, for unit testing the overloaded `init` version that allows injecting the `DataMapper` object may be called). The `init` method then uses the names provided by the `TDM_Map` system to set up a mapping between simulation variable pointers (provided by the `DataMapper`) and the internal DAVE-ML model variable pointers (provided by member function `getDaveMLVariablePointerFromName`).

During simulation run-time, the `DaveMLModel::update` method is called repeatedly to perform the following steps in turn:

- a) Copy values from the input simulation variables to the corresponding internal DAVE-ML model variables, using the pointers set up during initialization.
- b) Update the internal DAVE-ML Model.


For the `DaveMLTranslator` API, this is calling the `update()` method. (The bulk of the `DaveMLTranslator` processing occurs here. This interpreter recalculates all of the output variables values using the values of the input variables in this one update call.)

For the `Janus` API, this function is empty (no action - see below).

- c) Copy values from the internal DAVE-ML model variables to the corresponding simulation output variable pointers as setup during initialization.

For the `DaveMLTranslator` API, this is a data copy between pointers.

For the `Janus` API, this step is where the bulk of its processing takes place. The value of each output variable is requested in turn. If `Janus` determines that intermediate variables needed to determine this value are stale, they are recalculated. The returned result is then copied to the simulation variable pointer (Note that the `Janus` capability of only calculating some of the outputs is not used in this generalized access strategy.)

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 16 of 343 |

The generic interface provided by the DaveMIModel class was determined to be sufficient for access to the minimum features of both the DaveMLTranslator and Janus interpreters for general DAVE-ML models. This generic interface is shown in Table 1 below. Each subclass derived from DaveMIModel implements this interface. The suggested implementation of the update method is shown below the table.

Table 1 Generic Interpreter Interface Methods

| Method | Purpose |
|--|---|
| void copyInputs() | Copy input values from sim variables to internal DAVE-ML model variables |
| void copyOutputs() | Copy output values from internal DAVE-ML model variables to sim variables |
| void interpreterLoadAndCheck (const std::string& filePath, bool performCheckCases) | Command interpreter to: load DAVE-ML file perform DAVE-ML check cases (optional) |
| double* getDaveMIVariablePointerfromName (const std::string& name) | Return pointer corresponding to internal DAVE-ML variable "name" |
| void interpreterInitialize() | Command interpreter to set input variables to default values |
| void interpreterUpdate() | Command interpreter to update using the current input values already set (by copyInputs) and to copyOutputs |
| void interpreterTerminate() | Destroy the interpreter |
| void update() | "Template Method" design pattern: see below for implementation |

The "Template Method" DaveMIModel::update() is a generic recipe that all sub-classes implementing different interpreters can use to update their models. It is built up primarily of calls to the other generic interface functions.

In C++, this recipe is:


```
void update() {
    if (!isInterpreter()) {
        // set zeros into all outputs if a working interpreter is not available
        ... (implementation not shown here)
    } else {
        copyInputs();

        // update the model using the input values
        interpreterUpdate();

        copyOutputs();
    }
}
```

Two adapter classes were constructed:

- DaveMIModel is used to wrap a general DAVE-ML model intended to be embedded in user model class source code.
- DaveMIModelObject has a slightly different public interface making it more convenient to place a DAVE-ML model as a child of a top level simulation object of a Trick sim.

| | | | |
|---|---|---|---------------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 17 of 343 |

4.1.1 Lessons Learned

We found it valuable to have both the Janus and DaveMTranslator interpreters available. Janus is the more capable, providing ungridded table capability via the QHULL library. The two interpreters use different underlying XML libraries, so if parser problems or capability gaps were to be found for one interpreter, the other can be tried. One may have a faster run time performance for a particular problem than the other.

Execution speed using the interpreters was close to hand coded performance for the models we investigated (within a factor of 4). Should the interpreted performance prove inadequate for some problem, C source code can be auto-generated from DAVE-ML files using XSLT with some hand coded finishing work, or the algorithm can be fully hand coded from the DAVE-ML definition. The DAVE-ML internal checkData available with each model was found to be particularly valuable while integrating each DAVE-ML model.


4.2 Simulation Data Mapping, and Testing

During the course of this project, we developed a general DataMapper interface that was used to encapsulate the Trick Simulation Environment's system for returning memory pointers from variable names. The Trick system was accessed through this general interface so that a test-specific sub-class could be easily substituted for it during unit testing. This allowed testing of the DAVE-ML models separate from the Trick environment.

This system worked along with the TDM_Map system (see the next section). The DataMapper provided pointers from simulation variable names, while TDM_Map provided the correspondence between simulation variable names and internal DAVE-ML model variables. These two capabilities allowed the DaveMModel class (discussed previously), to hook up DAVE-ML models to the simulation via an XML file in a general way useful for all models.

4.3 TDM_Map: Trick to DAVE-ML Variable Name Mapping

A TDM_map class simply stores pairs of variable names. One name in a pair refers to a DAVE-ML model variable, while the other refers to a Trick model variable. An instance of a TDM-map is constructed from an XML file like the following, by calling the method TDM_make_map() :

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 18 of 343 |

```

<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE tdmmap SYSTEM "tdmmap.dtd">

<!-- Description: Example Trick/DAVEML Variable Name Map -->

<tdmmap version="1.0">
  <inputs>
    <varpair> <dave_var>vt</dave_var> <trick_var>f16.vtotal</trick_var> </varpair>
    <varpair> <dave_var>alpha</dave_var> <trick_var>f16.alpha</trick_var> </varpair>
    <varpair> <dave_var>beta</dave_var> <trick_var>f16.beta</trick_var> </varpair>
    <varpair> <dave_var>p</dave_var> <trick_var>f16.p</trick_var> </varpair>
    <varpair> <dave_var>q</dave_var> <trick_var>f16.q</trick_var> </varpair>
    <varpair> <dave_var>r</dave_var> <trick_var>f16.r</trick_var> </varpair>
    <varpair> <dave_var>el</dave_var> <trick_var>f16.el</trick_var> </varpair>
    <varpair> <dave_var>ail</dave_var> <trick_var>f16.ail</trick_var> </varpair>
    <varpair> <dave_var>rdr</dave_var> <trick_var>f16.rdr</trick_var> </varpair>
    <varpair> <dave_var>xcg</dave_var> <trick_var>f16.xcg</trick_var> </varpair>
  </inputs>

  <outputs>
    <varpair> <dave_var>cx</dave_var> <trick_var>f16.cx</trick_var> </varpair>
    <varpair> <dave_var>cy</dave_var> <trick_var>f16.cy</trick_var> </varpair>
    <varpair> <dave_var>cz</dave_var> <trick_var>f16.cz</trick_var> </varpair>
    <varpair> <dave_var>cl</dave_var> <trick_var>f16.cl</trick_var> </varpair>
    <varpair> <dave_var>cm</dave_var> <trick_var>f16.cm</trick_var> </varpair>
    <varpair> <dave_var>cn</dave_var> <trick_var>f16.cn</trick_var> </varpair>
  </outputs>
</tdmmap>

```

The following is an example usage of TDM_make_map(), a factory class of sorts, to create a TDM_map object:

```

#include "TDM_make_map.hh"
// Load and process the DAVE-ML to Trick mapping file
// and setup the mappings
TDM_map* tdmmap = NULL;
tdmmap = TDM_make_map(mapFilePath.c_str());

if (tdmmap != NULL) {
  int i;
  int n_inputs, n_outputs;
  const char* dvar;
  const char* tvar;

  n_inputs = tdmmap->NumberOfInputs();
  n_outputs = tdmmap->NumberOfOutputs();


  for (i=0; i<n_inputs; i++) {
    tdmmap->getInputVarPair( i, dvar, tvar);
    // save the name
  }

  for (i=0; i<n_outputs; i++) {
    tdmmap->getOutputVarPair( i, dvar, tvar);
    // save the name
  }

  // done with the map
  delete tdmmap;
  tdmmap = NULL;
}

```

Figure 6 below shows the relationships of the components of a TDM_map. Note that it closely matches the structure of the XML file. A TDM_component corresponds to an XML element. The TDM_map, TDM_varpairlist, and TDM_varpair each correspond to elements of the XML file.

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 19 of 343 |

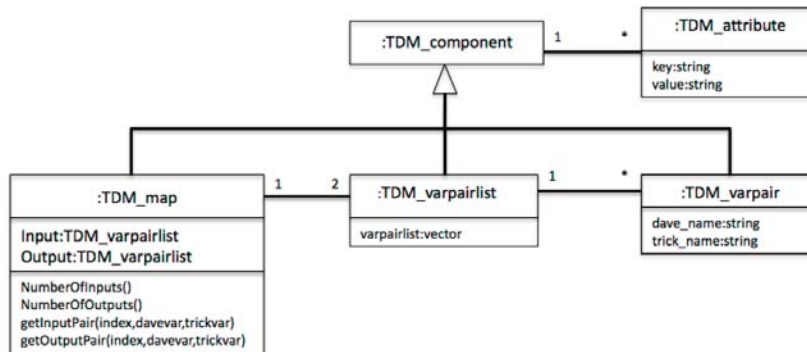



Figure 6. TDM_Map Software UML Class Diagram

A UML sequence diagram of the interactions is shown in Figure 7.

The purpose of `TDM_make_map()` is to parse the XML file and pass the root node of the parse tree to the `TDM_map` constructor so it can walk the tree, creating a in memory representation of the same information.

4.3.1 Lessons Learned

The `TDM_Map` system is independent of the simulation environment being used. It can provide XML file model hookup capability for any environment, as long as the variable names it correlates can be used by following software like our `DataMapper` class to find pointers to sim variables given their names, and the DAVE-ML interpreters are wrapped in a class with similar capabilities to `DaveMlModel` such that the available interpreter(s) can return pointers to internal DAVE-ML model variables from input variable names in a common way.

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 20 of 343 |

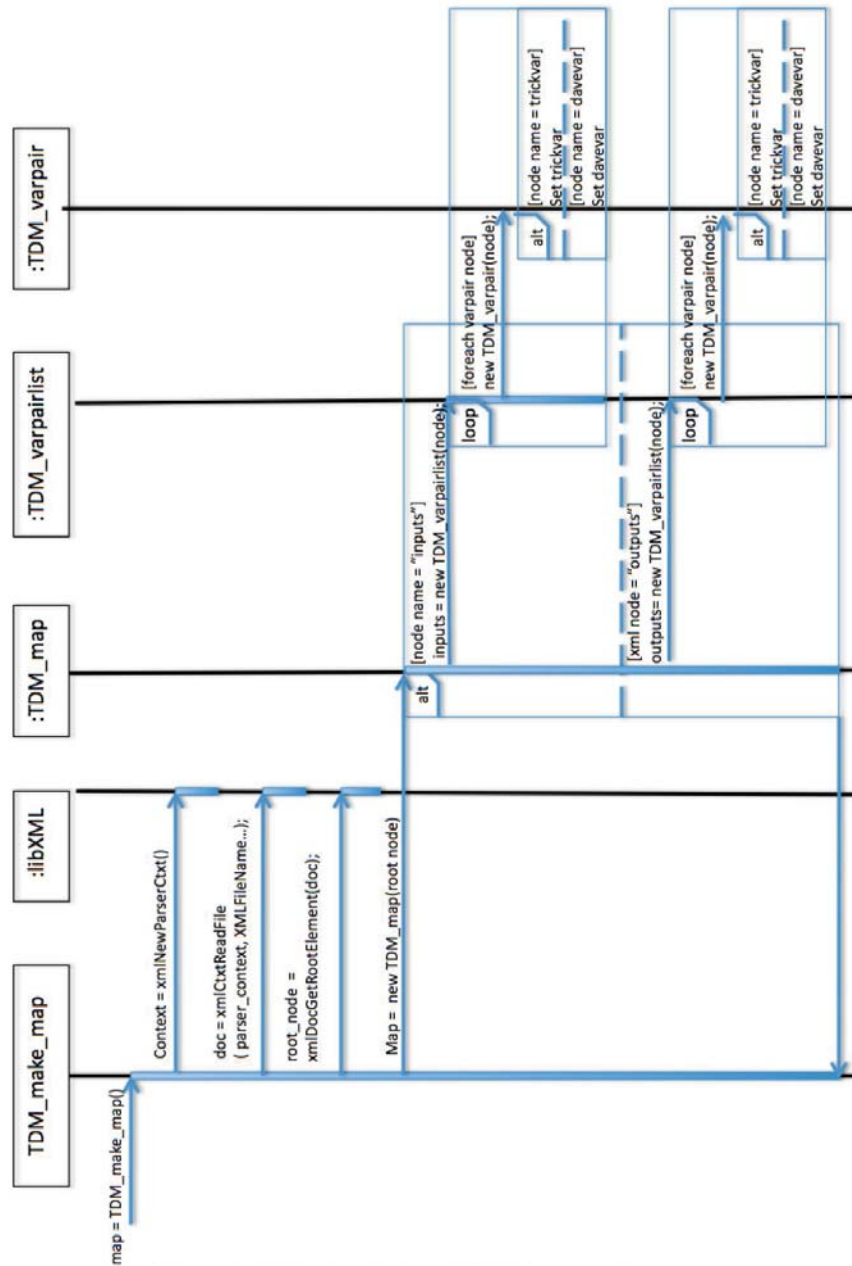



Figure 7. TDM_Map Software UML Sequence Diagram

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 21 of 343 |

4.4 Autocoding DAVE-ML to C via XSLT

4.4.1 Feasibility of Transforming a Legal DAVE-ML Model into Executable "C" Code.

DAVE-ML is an XML markup language for describing vehicle models.

DAVE-ML's grammar rules (syntax), which specify how elements can be legally ordered, are described by its DTD. The semantics of a DAVE-ML model file are conveyed by the definitions of its language-specific elements and attributes (specified in the DAVE-ML Reference(2)) and of course by the user-specific choices of those elements and attributes, ordered according to the grammar rules.

This investigation is an attempt to determine the extent to which the syntax and semantics of DAVE-ML sufficiently and unambiguously describe a model that can be transformed into executable "C" code.

The XML elements defined by DAVE-ML organize a lot of information about a model, including its definition, configuration history, data references, authorship, uncertainty and check data. The elements that we are concerned with in this particular exercise are those related to the definition of the executable model, in other words, those elements that would need to be translated into "C" to properly represent the model. Figure 8 shows these DAVE-ML elements and their dependencies.

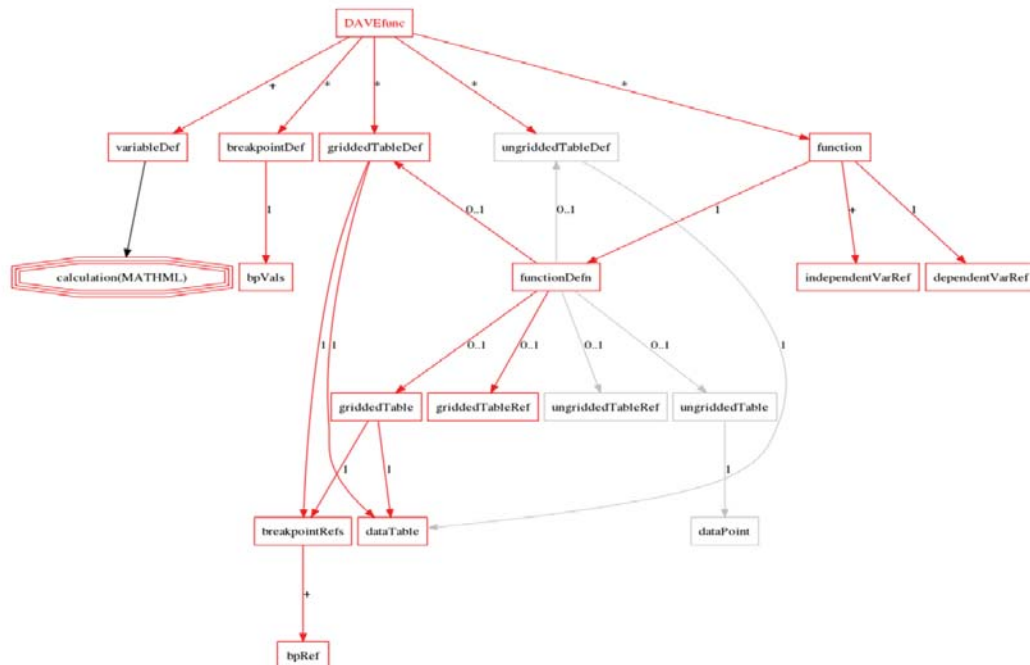



Figure 8. DAVEML Elements and Dependencies that are related to Code Generation

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h1 style="text-align: center;">Flight Simulation Model Exchange</h1> | | Page #: 22 of 343 |

Scope Limitations:

Because we have a limited amount of time, we'd like to concentrate on getting the most "bang for buck" with what time we have, therefore:

- Only "gridded" data will be supported.
- Only enough of the MathML(14) to transform the F-16 and HL-20 aero models will be processed.

Choice of XSLT:

Since DAVE-ML is an XML(15) based language, XSLT (Extensible Style-sheet Language for Transformations) is a natural means of transforming it.

- XSLT is widely used for transforming XML.
- It is an official recommendation of the World Wide Web Consortium (W3C).
- There are many freely available XSLT processors.

Working on Linux, we chose xsltproc, a tool in the GNOME XSLT library, because of its common availability.

4.4.2 Design - Mapping DAVE-ML Elements to "C" Code

The following sections map DAVE-ML elements to corresponding "C" code. They refer often to XSLT code in Listing 1 – DMLtoC.xsl by line number.

DAVEfunc Element

We will assume that the DAVEfunc element maps to a executable "C" model, because of our boundless optimism and because otherwise we would be admitting failure before we even got started. The general approach will be:

Generate the following in the following order:

| Line Number | Purpose |
|-------------|---|
| 33..34 | Necessary include files. |
| 41..43 | Variable Definitions generated from <i>variableDef</i> elements. |
| 50..52 | Breakpoint Definitions generated from <i>breakpointDef</i> elements. |
| 59..67 | Interpolation Data generated from <i>griddedTableDef</i> elements and <i>function</i> elements. |
| 70.. | In a function called update(), perform the following: |
| 78..80 | Variable Initialization also generated from <i>variableDef</i> elements. |
| 87..89 | Function calls generated from <i>function</i> elements |
| 96..98 | Assignment statements generated from <i>variableDef</i> elements. |


(Line numbers refer to those in Listing 1 – DMLtoC.xsl)

variableDef Element

A *variableDef* element maps to variable definition in "C". The name of the "C" variable can be taken from the @varID attribute (line 121). The initializer for the "C" variable can be taken from the @initialValue attribute. The type specifier for the "C" variable definition can probably, safely be assumed to be double.

```
double vt = 1.0;
```

Rather than creating initializers in the declaration, we initialized the variables with assignment statements (lines 78..80, 135).

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 23 of 343 |

calculation Element

A *calculation* element maps to the right side of an assignment statement, in which the “C” variable associated with the parent *variableDef* element, is assigned the value resulting from the evaluation of a “C” arithmetic expression, corresponding to the enclosed MathML expression (lines 346, 360).

Example C assignment statement:

```
cq2v = {cbar * (q / tv)};
```

The expression within a <math> element is defined recursively. An expression is defined as:

<cn> element (a number) OR
 <ci> element (an identifier) OR
 <apply> element, consisting of:
 an operator (<plus> | <minus> | <times> | ...) AND
 an aggregation of expressions).

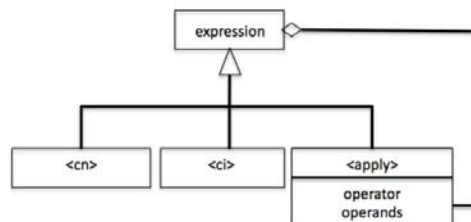


Figure 9. UML Diagram For MathML <math> Elements

If the expression is a <cn> element, then we need to emit the corresponding number.
 If the expression is a <ci> element, then we need to emit the corresponding identifier.
 If the expression is an <apply> element, then we need to first identify the operator and then process the remaining “sibling” operands, based on the operator that we found.

XSLT supports recursive template calls, so the transformations of plus, minus, times and divide (sub)expressions was straight forward. The one problem we ran into was how to transform a piecewise element into an expression suitable for the right hand side of an assignment. Though we haven’t yet had time to figure out how to do it, we still think it might be do-able; possibly by transformation of the piecewise element into a function which is then called on the left hand side of an assignment.


So that we didn’t run afoul of C’s operator precedence rules, we put parentheses around all of the sub-expressions generated from transformations of the <apply> element.

Whether or not all possible MathML expressions, that might legally appear in a calculation element, can be translated to a corresponding “C” expression, is still an open question.

function Element

A function element also maps to an assignment statement (line 184). In this assignment statement, the dependent variable, specified by the *dependentVarRef* element, is assigned the value returned by an interpolator function call. The interpolator function will take as its arguments:

- References to the independent variable(s), specified by the *independentVarRef* element and
- A reference to the interpolation data, associated with the *functionDefn* element.

| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 24 of 343 |

```
dependent_var = interpolation_fn( interpolation_data_ref,
                                independent_var_1, ..
                                , independent_var_n);
```

independentVarRef Element

An *independentVarRef* element maps to a “C” variable reference (line 209), that is: its name, which will be the same as the @varID attribute of the corresponding *variableDef* element.

dependentVarRef Element

An *independentVarRef* element likewise maps to a “C” variable reference whose name is the same as the @varID attribute of the corresponding *variableDef* element. Dependent variable references appear on the left side of the assignment from the interpolator function calls (line 186).

functionDefn Element

A *functionDefn* element would generally map to some data structure that would consolidate the data necessary to specify either a gridded or an un-gridded interpolator. The data structure would contain the following information:

gridded | ungridded
depending on the above type, either
the data structure that specifies a gridded interpolator
the data structure that specifies an ungridded interpolator.

Because of our initial decision to limit the scope to gridded interpolation, we don’t need to create this consolidation structure. We only use the structure necessary for gridded data.

griddedTable Element

A *griddedTable* element maps to an instance of some structured data type that consolidates the data necessary to specify a gridded interpolator.

The data type would need to contain the following information:

- An ordered collection of (size /reference) pairs, one for each breakpoint array associated with the gridded interpolator,
- The size (cardinality) of the above collection,
- A reference to the data within which we are interpolating.


A unique identity for an instance of this “consolidation” data structure is needed. It might conceivably be derived from the @name attribute of the *griddedTable* element. A problem with this is that the @name attribute is not guaranteed (by the DTD) to exist, and it is not guaranteed to be unique.

A workaround is that its identity can be derived from our knowledge that a *griddedTable* element is only contained in a *functionDefn* element, which is only contained in a *function* element which contains one *independentVarRef* element, which has a unique name.

griddedTableDef Element

A *griddedTableDef* element maps to an instance of a data structure containing exactly the same type of information as the *griddedTable* element (above).

A unique identity for an instance of this “consolidation” data structure is also needed. A *griddedTableDef* may have an @gtID attribute, but it is not guaranteed to exist. It can’t derive an identity from its unique existence in a parent element with a unique identity, because it can be a child of the root element *DAVEfunc*. In this case a unique

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | Page #: 25 of 343 |

identity can't be derived from a parent element's identity as it was in the case of the *griddedTable* element, because the parent element is the root element.

dataTable Element

A *dataTable* element maps to an array of type double (line 326). The identity of the array is derived from the identity of the parent *<griddedTableDef>* or *<griddedTable>*.

```
double CX_table_data_table[] = {
    -.099,-.081,-.081,-.063,-.025,.044,.097,.113,.145,.167,.174,.166,
    -.048,-.038,-.040,-.021,.016,.083,.127,.137,.162,.177,.179,.167,
    -.022,-.020,-.021,-.004,.032,.094,.128,.130,.154,.161,.155,.138,
    -.040,-.038,-.039,-.025,.006,.062,.087,.085,.100,.110,.104,.091,
    -.083,-.073,-.076,-.072,-.046,.012,.024,.025,.043,.053,.047,.040
};
```

Workaround for the Gridded Table Identities:

In lines 59 .. 67, interpolation data structures are selected and transformed by processing both *griddedTableDef* elements (template name = *interp_data_from_gridded_table*) and function elements (template name = *interp_data_from_function*) at the top level (to extract embedded *griddedTableDef* and *GriddedTable* elements).

The “*interp_data_from_gridded_table*” template takes an identity parameter (*interpID*). From this identity, identifiers for the components of the corresponding “C” structures are derived.

Line 60, which processes top-level *griddedTableDef* elements, calls the “*interp_data_from_gridded_table*” template (line 227) using the *@gtID* as the identity parameter to generate interpolation data structures.


Line 66 calls the “*interp_data_from_function*” template (line 161) which in turn calls the “*interp_data_from_gridded_table*” template using the dependent variable as the identity parameter for both embedded *griddedTable* and *griddedTableDef* elements.

breakpointRefs Element

A *breakpointRefs* element represents a collection of breakpoint references. It maps to two arrays (line 280). The first array is a list of pointers to breakpoint arrays. The second is an array of the sizes of each of the arrays pointed to by the first. The names of the arrays are derived from the identity of the parent of the *<breakpointRefs>* element.

```
double* CX_table_breakpointRefs[] = {DE1, ALPHA1};

int CX_table_breakpointSizes[] = {
    (sizeof(DE1)/sizeof(DE1[0])),
    (sizeof(ALPHA1)/sizeof(ALPHA1[0]))
};
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 26 of 343 |

bpRef Element

A breakpoint reference is the value of the @bpID attribute of the bpRef element.

griddedTableRef

A griddedTableRef element maps to a “C” variable reference, i.e., its name, which will be the same as the @gtID attribute of the corresponding griddedTableDef element.

breakpointDef Element

A breakpointDef element maps to a “C” array of type double. The name of the array is the value of the @bpID attribute of the breakpointDef element. The contents of the array initializer are the values contained within the bpVals element.

```
double ALPHA1[] = {-10.,-5.,0.,5.,10.,15.,20.,25.,30.,35.,40.,45.};
```

bpVals Element


A bpVals element maps the numbers within the initializer for the array corresponding to the breakpointDef element.

4.4.3 Lessons Learned

Because we were able to transform the HL-20 and F-16 DAVE-ML files to executable “C” models, it appears the development of a general process is very feasible.

A griddedTableDef element at the root level of a legal (according to the DTD) DAVE-ML file is not required to have an @gtID. This makes it impossible to guarantee that that file can be transformed to “C”. In order to make that possible, a user would currently be required to manually verify that griddedTablesDefs did have gtIDs.

Although we’ve only created transformations for a subset of MathML operators, and we’ve not yet determined how to transform *piecewise* elements, we do believe that there is likely a solution.


| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h1 style="text-align: center;">Flight Simulation Model Exchange</h1> | | Page #: 27 of 343 |

Listing 1 – DMLtoC.xsl

```

1 <!-- =====
2   DAVE-ML to "C" Language Translator
3
4   Development Task: NESC Flight Simulation Model Exchange
5   Development Lead: E. Bruce Jackson (bruce.jackson@nasa.gov)
6   Developer: John M. Penn (john.m.penn@nasa.gov) (L3 Communications)
7   Developing Organization:
8     Simulation and Graphics Branch
9     Software, Robotics and Simulation Division
10    Engineering Directorate
11    NASA Johnson Space Center
12
13    This transform is an artifact of a study. It was created to provide just enough
14    functionality to transform the two DAVEML-file examples that we had and is NOT
15    GUARANTEED to work for all possible DAVEML files that can be created. It is not
16    a finished product, but it might be a useful start. John M. Penn
17    =====
18    $Id: DMLtoC.xsl 119 2010-09-28 14:30:23Z mjessick $
19 -->
20
21 <xsl:transform version="1.0"
22   xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
23
24   <xsl:output method="text"/>
25   <xsl:strip-space elements="*" />
26
27 <!-- =====
28   Transform DAVE-ML to C.
29   =====
30 -->
31 <xsl:template match="/DAVEfunc">
32
33   <xsl:text>#include "mlinterp.h"&#xA;</xsl:text>
34   <xsl:text>#include "math.h"&#xA;</xsl:text>
35
36   <xsl:text>&#xA;</xsl:text>
37   <xsl:text>/* =====&#xA;</xsl:text>
38   <xsl:text>/* ==      VARIABLE DECLARATIONS      ==&#xA;</xsl:text>
39   <xsl:text>/* =====&#xA;</xsl:text>
40
41   <xsl:for-each select="variableDef">
42     <xsl:call-template name="var_declaration" />
43   </xsl:for-each>
44
45   <xsl:text>&#xA;</xsl:text>
46   <xsl:text>/* =====&#xA;</xsl:text>
47   <xsl:text>/* ==      BREAKPOINT DECLARATIONS      ==&#xA;</xsl:text>
48   <xsl:text>/* =====&#xA;</xsl:text>
49
50   <xsl:for-each select="breakpointDef">
51     <xsl:call-template name="bp_declaration" />
52   </xsl:for-each>
53
54   <xsl:text>&#xA;</xsl:text>
55   <xsl:text>/* =====&#xA;</xsl:text>
56   <xsl:text>/* ==      INTERPOLATION FUNCTION DATA      ==&#xA;</xsl:text>
57   <xsl:text>/* =====&#xA;</xsl:text>
58
59   <xsl:for-each select="griddedTableDef">
60     <xsl:call-template name="interp_data_from_griddedTable">


```

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 28 of 343 |

```

61         <xsl:with-param name="interpID" select="@gtID"/>
62         </xsl:call-template>
63     </xsl:for-each>
64
65     <xsl:for-each select="function">
66         <xsl:call-template name="interp_data_from_function"/>
67     </xsl:for-each>
68
69     <xsl:text>&#xA;</xsl:text>
70     <xsl:text>void update() {</xsl:text>
71     <xsl:text>&#xA;</xsl:text>
72
73     <xsl:text>&#xA;</xsl:text>
74     <xsl:text>/* =====</xsl:text>
75     <xsl:text>VARIABLE INITIALIZATION</xsl:text>
76     <xsl:text>===== */</xsl:text>
77
78     <xsl:for-each select="variableDef">
79         <xsl:call-template name="var_initialization" />
80     </xsl:for-each>
81
82     <xsl:text>&#xA;</xsl:text>
83     <xsl:text>/* =====</xsl:text>
84     <xsl:text>FUNCTION CALLS</xsl:text>
85     <xsl:text>===== */</xsl:text>
86
87     <xsl:for-each select="function">
88         <xsl:call-template name="interp_call_from_function"/>
89     </xsl:for-each>
90
91     <xsl:text>&#xA;</xsl:text>
92     <xsl:text>/* =====</xsl:text>
93     <xsl:text>CALCULATIONS</xsl:text>
94     <xsl:text>===== */</xsl:text>
95
96     <xsl:for-each select="variableDef/calculation">
97         <xsl:call-template name="var_calculation" />
98     </xsl:for-each>
99
100    <xsl:text>&#xA;</xsl:text>
101    <xsl:text>}</xsl:text>
102    <xsl:text>&#xA;</xsl:text>
103
104    <xsl:text>int main(int argc, char* argv[]) {</xsl:text>
105    <xsl:text>&#xA;</xsl:text>
106    <xsl:text>update();</xsl:text>
107    <xsl:text>&#xA;</xsl:text>
108    <xsl:text>return(0);</xsl:text>
109    <xsl:text>&#xA;</xsl:text>
110    <xsl:text>}</xsl:text>
111    <xsl:text>&#xA;</xsl:text>
112
113 </xsl:template>
114
115
116
117 <!-- =====
118 Convert a <variableDef> element to a "C" language variable declaration.
119 =====>
120 -->


```

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h1 style="text-align: center;">Flight Simulation Model Exchange</h1> | | Page #: 29 of 343 |

```

121 <xsl:template name="var_declaration" match="variableDef">
122   <xsl:text>double </xsl:text>
123   <xsl:value-of select="@varID"/>
124   <xsl:text>;</xsl:text>
125   <xsl:text> //</xsl:text>
126   <xsl:value-of select="@name"/>
127   <xsl:text> &#xA;</xsl:text>
128 </xsl:template>
129
130 <!-- =====
131   Generate variable initialization code for those variables that have initialValue
132   attributes.
133   =====
134 -->
135 <xsl:template name="var_initialization" match="variableDef">
136   <xsl:if test="@initialValue">
137     <xsl:value-of select="@varID"/>
138     <xsl:text> = </xsl:text>
139     <xsl:value-of select="@initialValue"/>
140     <xsl:text>;&#xA;</xsl:text>
141   </xsl:if>
142 </xsl:template>
143
144 <!-- =====
145   Convert a <breakpointDef> element to a "C" language array of doubles.
146   =====
147 -->
148 <xsl:template name="bp_declaration" match="breakpointDef">
149   <xsl:text>double </xsl:text>
150   <xsl:value-of select="@bpID"/>
151   <xsl:text>[] = {</xsl:text>
152   <xsl:value-of select="bpVals"/>
153   <xsl:text>};</xsl:text>
154   <xsl:text> &#xA;</xsl:text>
155 </xsl:template>
156
157 <!-- =====
158   Extract interpolation data and generate corresponding "C" data structures.
159   =====
160 -->
161 <xsl:template name="interp_data_from_function" select="function">
162
163   <xsl:variable name="depVarId" select="dependentVarRef/@varID"/>
164
165   <xsl:for-each select="functionDefn/griddedTableDef">
166     <xsl:call-template name="interp_data_from_griddedTable">
167       <xsl:with-param name="interpID" select="concat($depVarId,'_interp')"/>
168     </xsl:call-template>
169   </xsl:for-each>
170
171   <xsl:for-each select="functionDefn/griddedTable">
172     <xsl:call-template name="interp_data_from_griddedTable">
173       <xsl:with-param name="interpID" select="concat($depVarId,'_interp')"/>
174     </xsl:call-template>
175   </xsl:for-each>
176
177 </xsl:template>
178
179
180 <!-- =====

```

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | Page #: 30 of 343 |

```

181      Generate interpolator function calls.
182      =====
183      -->
184      <xsl:template name="interp_call_from_function" select="function">
185
186          <xsl:variable name="depVarId" select="dependentVarRef/@varID"/>
187
188          <xsl:value-of select="$depVarId"/>
189          <xsl:text> = </xsl:text>
190
191          <xsl:for-each select="functionDefn/griddedTable">
192              <xsl:text>ml_interp( </xsl:text>
193              <xsl:text> &#x26; </xsl:text>
194              <xsl:value-of select="concat($depVarId, '_interp')"/>
195          </xsl:for-each>
196
197          <xsl:for-each select="functionDefn/griddedTableDef">
198              <xsl:text>ml_interp( </xsl:text>
199              <xsl:text> &#x26; </xsl:text>
200              <xsl:value-of select="concat($depVarId, '_interp')"/>
201          </xsl:for-each>
202
203          <xsl:for-each select="functionDefn/griddedTableRef">
204              <xsl:text>ml_interp( </xsl:text>
205              <xsl:text> &#x26; </xsl:text>
206              <xsl:value-of select="@gtID"/>
207          </xsl:for-each>
208
209          <xsl:for-each select="independentVarRef">
210              <xsl:text>, </xsl:text>
211              <xsl:value-of select="@varID"/>
212          </xsl:for-each>
213          <xsl:text> ) </xsl:text>
214          <xsl:text> &#xA; </xsl:text>
215      </xsl:template>
216
217
218
219      <!-- =====
220      Convert a <griddedTableDef> or a <griddedTable> to corresponding "C" data
221      structures.
222
223      Parameter:
224      interpID - Interpolator ID.
225      =====
226      -->
227      <xsl:template name="interp_data_from_griddedTable"
228          select="griddedTableDef|griddedTable">
229
230          <xsl:param name="interpID" select="FIXME"/>
231
232          <xsl:text>&#xA; </xsl:text>
233          <xsl:text>/* INTERPOLATION DATA : </xsl:text>
234          <xsl:value-of select="$interpID"/>
235          <xsl:text> */ &#xA; &#xA; </xsl:text>
236
237          <xsl:for-each select="breakpointRefs">
238              <xsl:call-template name="gen_C_bpref_arrays">
239                  <xsl:with-param name="interpID" select="$interpID"/>
240              </xsl:call-template>

```




NASA Engineering and Safety Center
Technical Assessment Report

Document #:
**NESC-RP-
09-00598**


Version:
1.0

Title:

Flight Simulation Model Exchange

Page #:
31 of
343


```
241 </xsl:for-each>
242
243 <xsl:for-each select="dataTable">
244   <xsl:call-template name="gen_C_data_table">
245     <xsl:with-param name="interpID" select="$interpID"/>
246   </xsl:call-template>
247 </xsl:for-each>
248
249 <xsl:text>MLInterp </xsl:text>
250 <xsl:value-of select="$interpID"/>
251 <xsl:text>= {&#xA;</xsl:text>
252 <xsl:text>    </xsl:text>
253 <xsl:value-of select="$interpID"/>
254 <xsl:text>__breakpointRefs,&#xA;</xsl:text>
255 <xsl:text>    </xsl:text>
256 <xsl:value-of select="$interpID"/>
257 <xsl:text>__data_table,&#xA;</xsl:text>
258 <xsl:text>    </xsl:text>
259 <xsl:value-of select="$interpID"/>
260 <xsl:text>__breakpointSizes,&#xA;</xsl:text>
261 <xsl:text>    </xsl:text>
262 <xsl:text>(sizeof(</xsl:text>
263 <xsl:value-of select="$interpID"/>
264 <xsl:text>__breakpointSizes)/sizeof(</xsl:text>
265 <xsl:value-of select="$interpID"/>
266 <xsl:text>__breakpointSizes[0]))&#xA;</xsl:text>
267 <xsl:text>};&#xA;</xsl:text>
268
269 </xsl:template>
270
271
272 <!-- =====
273 Convert <breakpointRefs> element to an array of pointers to breakpoint arrays
274 generated by the "bp_declaration" template above.
275
276 Parameter:
277   interpID - Interpolator ID.
278 =====
279 -->
280 <xsl:template name="gen_C_bpref_arrays" match="breakpointRefs">
281
282   <xsl:param name="interpID"/>
283
284   <xsl:text>double* </xsl:text>
285   <xsl:value-of select="$interpID"/>
286   <xsl:text>__breakpointRefs[] = {</xsl:text>
287
288   <xsl:for-each select="child::*">
289     <xsl:value-of select="self::bpRef/@bpID"/>
290     <xsl:if test="not(position()=last())">
291       <xsl:text>,</xsl:text>
292     </xsl:if>
293   </xsl:for-each>
294   <xsl:text>};</xsl:text>
295   <xsl:text>&#xA;</xsl:text>
296
297   <xsl:text>int </xsl:text>
298   <xsl:value-of select="$interpID"/>
299   <xsl:text>__breakpointSizes[] = {</xsl:text>
300   <xsl:text>&#xA;</xsl:text>
```

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | Page #: 32 of 343 |

```

301
302     <xsl:for-each select="child::*">
303         <xsl:text> </xsl:text>
304         <xsl:text>(sizeof(</xsl:text>
305         <xsl:value-of select="self::bpRef/@bpID"/>
306         <xsl:text>)/sizeof(</xsl:text>
307         <xsl:value-of select="self::bpRef/@bpID"/>
308         <xsl:text>[0]))</xsl:text>
309         <xsl:if test="not(position()=last())">
310             <xsl:text>, </xsl:text>
311             <xsl:text>&#xA;</xsl:text>
312         </xsl:if>
313     </xsl:for-each>
314
315     <xsl:text>&#xA;</xsl:text>
316     <xsl:text>}</xsl:text>
317     <xsl:text>&#xA;</xsl:text>
318 </xsl:template>
319
320
321
322 <!-- =====
323 The data table is part of the interpolation data.
324 =====
325 -->
326 <xsl:template name="gen_C_data_table" match="dataTable">
327
328     <xsl:param name="interpID" select="FIXME"/>
329
330     <xsl:text>double </xsl:text>
331     <xsl:value-of select="$interpID"/>
332     <xsl:text>__data_table[] = {</xsl:text>
333     <xsl:text>&#xA;</xsl:text>
334     <xsl:value-of select="."/>
335     <xsl:text>&#xA;</xsl:text>
336     <xsl:text>}</xsl:text>
337     <xsl:text>&#xA;</xsl:text>
338
339 </xsl:template>
340
341 <!-- =====
342 Generate an assignment statement from a <calculation> element and the @varID
343 attribute of it's parent <variableDef> element.
344 =====
345 -->
346 <xsl:template name="var_calculation" match="calculation">
347     <xsl:value-of select=".,/@varID"/>
348     <xsl:text> = </xsl:text>
349     <xsl:apply-templates select="math"/>
350     <xsl:text>&#xA;</xsl:text>
351 </xsl:template>
352
353
354 <!-- =====
355 MATHML
356 =====
357 -->
358
359 <!-- Generate an C-language math expression from a <math> element. -->
360 <xsl:template match="math">


```

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 33 of 343 |

```

361     <xsl:apply-templates select="apply"/>
362 </xsl:template>
363
364 <!-- Generate an C-language math expression from an <apply> element
365      (within a <math> element), -->
366 <xsl:template match="apply">
367     <xsl:text></xsl:text>
368     <xsl:apply-templates select="plus"/>
369     <xsl:apply-templates select="minus"/>
370     <xsl:apply-templates select="times"/>
371     <xsl:apply-templates select="divide"/>
372     <xsl:apply-templates select="power"/>
373     <xsl:apply-templates select="abs"/>
374     <xsl:apply-templates select="piecewise"/>
375     <xsl:text></xsl:text>
376 </xsl:template>
377
378 <xsl:template match="piecewise">
379     <xsl:text> 0 /*FIXME: piecewise needs handcoding help. */</xsl:text>
380 </xsl:template>
381
382 <xsl:template match="piece">
383     <xsl:for-each select="child::*">
384
385         <xsl:if test="not(position()=first())">
386             <xsl:apply-templates select="self::apply"/>
387             <xsl:apply-templates select="self::ci"/>
388             <xsl:apply-templates select="self::cn"/>
389         </xsl:if>
390
391     </xsl:for-each>
392 </xsl:template>
393
394 <xsl:template match="otherwise">
395 </xsl:template>
396
397 <!-- Generate an addition sub-expression from a <plus> element. -->
398 <xsl:template match="plus">
399     <xsl:for-each select="following-sibling::*">
400         <xsl:apply-templates select="self::apply"/>
401         <xsl:apply-templates select="self::ci"/>
402         <xsl:apply-templates select="self::cn"/>
403         <xsl:if test="not(position()=last())">
404             <xsl:text> + </xsl:text>
405         </xsl:if>
406     </xsl:for-each>
407 </xsl:template>
408
409 <!-- Generate a unary-minus sub-expression from a <minus> element. -->
410 <xsl:template match="minus">
411     <xsl:for-each select="following-sibling::*">
412         <xsl:text> - </xsl:text>
413         <xsl:apply-templates select="self::apply"/>
414         <xsl:apply-templates select="self::ci"/>
415         <xsl:apply-templates select="self::cn"/>
416     </xsl:for-each>
417 </xsl:template>
418
419 <!-- Generate a multiplication sub-expression from a <times> element. -->
420 <xsl:template match="times">


```

| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 34 of 343 |

```

421   <xsl:for-each select="following-sibling::*">
422     <xsl:apply-templates select="self::apply"/>
423     <xsl:apply-templates select="self::ci"/>
424     <xsl:apply-templates select="self::cn"/>
425     <xsl:if test="not(position()=last())">
426       <xsl:text> * </xsl:text>
427     </xsl:if>
428   </xsl:for-each>
429 </xsl:template>
430
431 <!-- Generate a division sub-expression from a <divide> element. -->
432 <xsl:template match="divide">
433   <xsl:for-each select="following-sibling::*">
434     <xsl:apply-templates select="self::apply"/>
435     <xsl:apply-templates select="self::ci"/>
436     <xsl:apply-templates select="self::cn"/>
437     <xsl:if test="not(position()=last())">
438       <xsl:text> / </xsl:text>
439     </xsl:if>
440   </xsl:for-each>
441 </xsl:template>
442
443 <!-- Generate a exponentiation sub-expression, implemented as a call
444 to pow(), from a <power> element. -->
445 <xsl:template match="power">
446   <xsl:text>pow(</xsl:text>
447   <xsl:for-each select="following-sibling::*">
448     <xsl:apply-templates select="self::apply"/>
449     <xsl:apply-templates select="self::ci"/>
450     <xsl:apply-templates select="self::cn"/>
451     <xsl:if test="not(position()=last())">
452       <xsl:text>,</xsl:text>
453     </xsl:if>
454   </xsl:for-each>
455   <xsl:text>)</xsl:text>
456 </xsl:template>
457
458 <!-- Generate a absolute-value sub-expression, implemented as a call
459 to abs() from a <abs> element. -->
460 <xsl:template match="abs">
461   <xsl:text>fabs(</xsl:text>
462   <xsl:for-each select="following-sibling::*">
463     <xsl:apply-templates select="self::apply"/>
464     <xsl:apply-templates select="self::ci"/>
465     <xsl:apply-templates select="self::cn"/>
466   </xsl:for-each>
467   <xsl:text>)</xsl:text>
468 </xsl:template>
469
470 <!-- Generate a variable identifier from a <ci> element. -->
471 <xsl:template match="ci">
472   <xsl:value-of select="."/>
473 </xsl:template>
474
475 <!-- Generate a floating point number from a <cn> element. -->
476 <xsl:template match="cn">
477   <xsl:value-of select="."/>
478 </xsl:template>
479
480 </xsl:transform>

```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 35 of 343 |

Listing 2 - mlinterp.h

```

1  #ifndef ML_INTERP_H
2  #define ML_INTERP_H
3
4  /*
5   Development Task: NESC Flight Simulation Model Exchange
6   Development Lead: Bruce E. Jackson (bruce.jackson@nasa.gov)
7   Developer: John M. Penn (john.m.penn@nasa.gov) (L3 Communications)
8
9   Developing Organization:
10    Simulation and Graphics Branch
11    Software, Robotics and Simulation Division
12    Engineering Directorate
13    NASA Johnson Space Center
14
15    $Id: mlinterp.h 100 2010-08-23 20:49:57Z penn $
16 */
17
18 #ifdef __cplusplus
19 extern "C" {
20 #endif
21
22 typedef struct {
23     double** bpRef;      /*< Array (of length n [below]) of pointers to the breakpoint arrays.*/
24     double* data_table; /*< Interpolation data.*/
25     int* bpSize;         /*< Array that specifies the size of each breakpoint array.*/
26     int n;               /*< Number of independent variables. Same as number of breakpoint arrays.*/
27 } MLInterp;
28
29 /**
30  Multi-linear interpolation function.
31  @param interp_obj - Interpolator object.
32  @param param1 - first independent variable/parameter.
33  @return - interpolated value.
34 */
35 double ml_interp( MLInterp* interp_obj, double param1, ... );
36
37 #ifdef __cplusplus
38 }
39 #endif
40 #endif

```

4.5 HL-20 Auto-Landing Simulation


The FSME program leveraged the existing DAVE-ML HL-20 aerodynamic model to practice transferring an extensive aerodynamic model between organizations and building a simulation from it.

At NASA/JSC, we built up a new HL-20 simulation using the Trick Simulation Environment and the JSC Engineering Orbital Dynamics (JEOD) models as a base. We extended JEOD's aerodynamic model hook and built an object oriented class system for embedding four different selectable HL-20 aero model implementations into the simulation. Along the way, general methods of connecting internal DAVE-ML interpreter variables to simulation variables were created. (The software integration was discussed in more detail in previous sections.)

The new simulation results were reviewed against previously published results including:

- Internal DAVE-ML checkData cases for the HL-20 aero model(16)(17), run through the two interpreters,
- Visual comparison with the step response plots reported in TM107580(16),
- Visual comparison with the published trajectory of TM107580(16).

An example pitch-step response, comparing the expected result as published in TM107580 to the Trick simulation result is shown in Figures 10 and 11.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 36 of 343 |

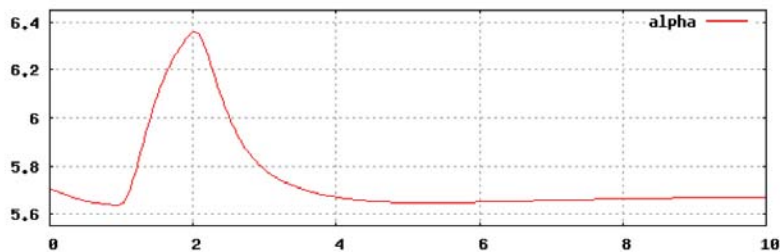


Figure 10. HL-20 Trick Sim, Pitch Pulse, Angle of Attack Trace

HL-20 Dynamic Check Case Data Plots 911206
Alt Pitch Stick Pulse at 300 KEAS, 10,000 ft

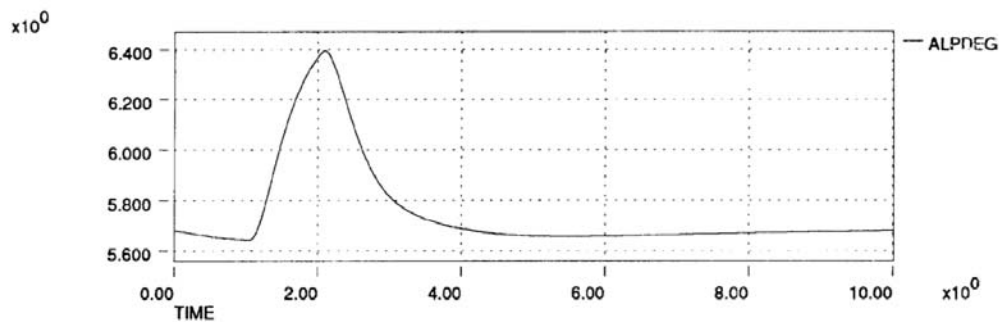



Figure 11. TM 107580 Pitch Pulse, Angle of Attack Trace

The trajectory comparing to the single case documented in TM 107580 was in rough agreement, although the precision of the visual comparison was not high, due to the lack of digital comparison profiles.

Several representative trajectory profile plots for approach along a 135 degree heading with a left turn around the Heading Alignment Cylinder (HAC) to a final approach along a 0 degree heading are shown in Figure 12 and 13 below. Note that this was the trajectory used for the Execution Time Study reported in the next section.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 37 of 343 |

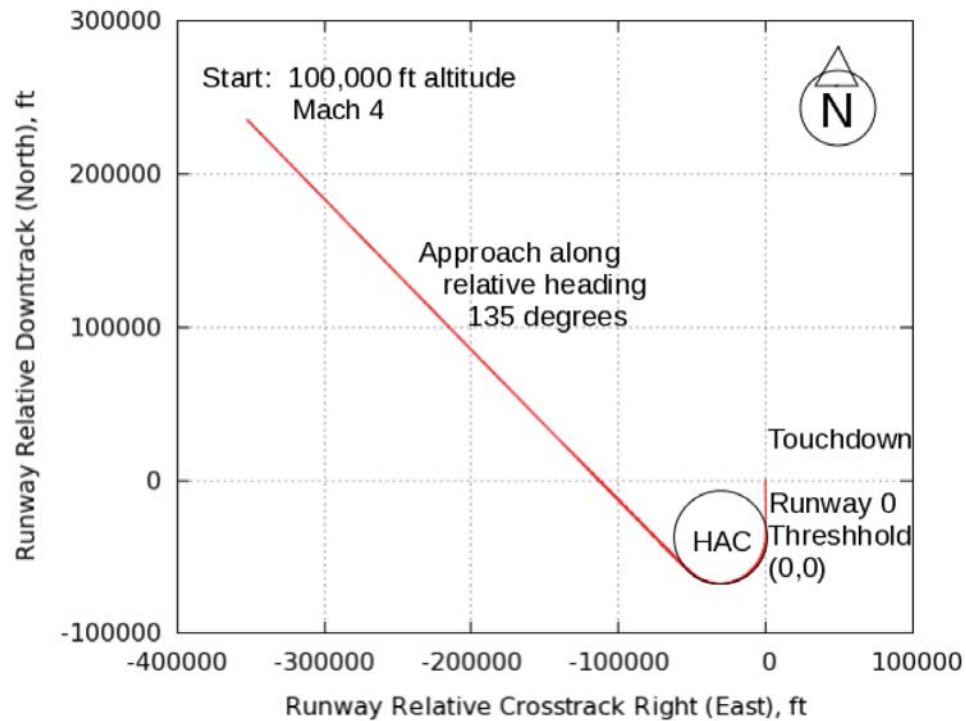



Figure 12. HL-20 Auto-Landing Trajectory, Overhead Map

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 38 of 343 |

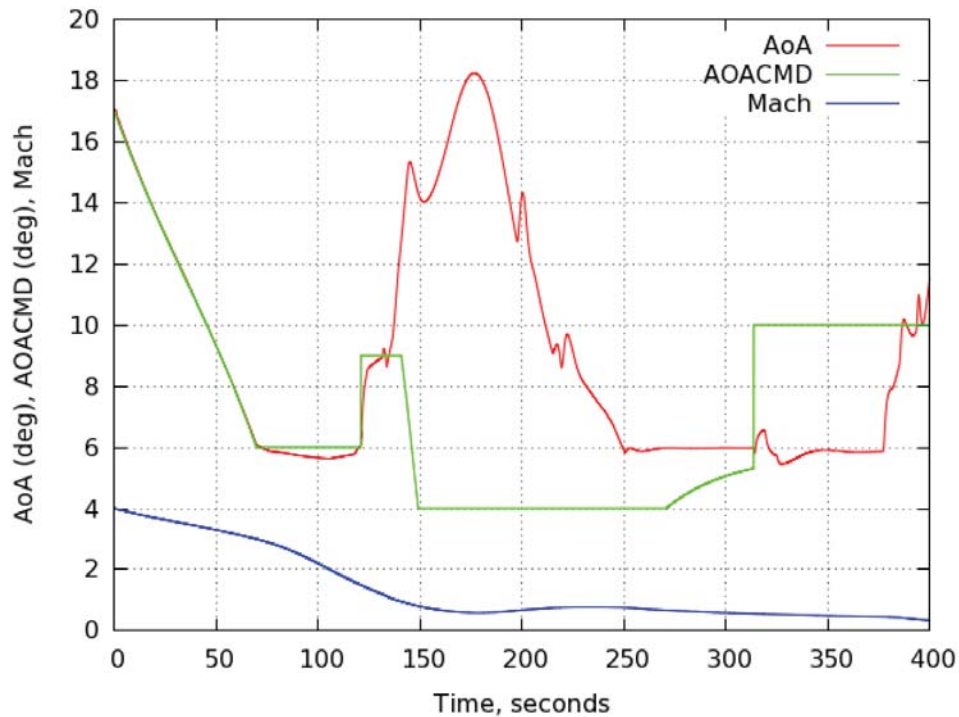



Figure 13. HL-20 Auto-Landing Trajectory, Angle of Attack (AoA) and Mach Profiles

The GN&C algorithm as auto-coded and integrated into this simulation may be operating differently in the supersonic regime than the legacy TM107580 algorithm(16). The ability to hold the commanded angle-of-attack seems reduced. This may point to a lingering algorithm re-hosting or auto-coding issue. Since the use of the simulation was primarily to integrate and evaluate the DAVE-ML based aerodynamic model, rather than the auto-coded GN&C algorithm, further investigation of this anomaly was suspended in favor of other tasks.

It is interesting to note the high degree of uniformity among the trajectories from all four versions of the DAVE-ML HL-20 aero model. As seen in Table 2, the touchdown points after 400 seconds of flight are identical for the three models interpreting or generated from the same DAVE-ML file, and different from the legacy hand coded C model by less than 2 feet.

Table 2. Touchdown Conditions Compared For The Four HL-20 Aero Model Versions

| Aero Model | Runway Relative Downtrack, ft | Runway Relative Crosstrack, ft |
|-----------------------|-------------------------------|--------------------------------|
| DaveMTranslator | 420.723151 | -20.102880 |
| Janus | 420.723151 | -20.102880 |
| XSLT Generated C code | 420.723151 | -20.102880 |
| Legacy Hand Coded C | 418.834007 | -20.133210 |

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 39 of 343 |

5.0 EXECUTION TIME STUDY OF DAVE-ML INTERPRETERS

This task compared the execution time of four versions of the HL-20 aerodynamic model using a single auto-landing scenario as the duty cycle. The execution time taken to process a single update of the HL-20 aerodynamic model was measured for the following versions of the model:

- DaveMTranslator DAVE-ML interpreter,
- Janus DAVE-ML interpreter,
- XSLT generated from DAVE-ML, with hand finishing,
- Legacy hand coded C version of the model.

The intent of this study was to measure the execution time of the different model implementations as embedded within a representative Trick/JEOD installation, over a single representative trajectory for a large DAVE-ML model, and a single computer system. (Additional constraints are discussed below under "Weaknesses".)

Note that although the HL-20 aero model has many table look-ups, they all use the simplest linear interpolation technique. While it can be considered "large", it likely falls short of "complex" relative to the full spectrum of possible DAVE-ML models.

5.1 Trick Job Timing System

The Trick Simulation Environment job timing system was used to collect the data. This system uses the Linux `clock_gettime(CLOCK_REALTIME)` function and provides results to microsecond resolution. This function uses the Intel hardware "RDTSC time stamp counter" for the test computer used.

The Trick job that includes the JEOD aero_drag function was measured. A small amount of administrative code calculating angle of attack and sideslip from body velocity inputs, and copying input values into the DAVE-ML model, and copying output values out of the DAVE-ML model, was included in each measurement. Note that this is several levels above the interpreter. It was assumed that the cost of these overhead routines is small in comparison to the time required to perform the DAVE-ML model calculations in the interpreter, and would be approximately the same for each of the four tested versions of the HL-20 aero model.


Because the Trick job timing system does not allow the collection of data for "derivative" type job calls (which is the job class appropriate for aero model jobs), an additional job was programmed to occur outside the numerical integration collection of aerodynamic forces. Because these additional timing jobs are interspersed with the normal derivative jobs (in this case, 4 calls per simulation dynamics frame for the Runge-Kutta fourth order integration technique), the effect of the derivative jobs on the measurements is unclear. It is conceivable that optimizations inside the interpreters could allow the measured jobs to perform better than the derivative jobs which could not be measured using the standard Trick system.

5.2 Test Computer and Operating System Specifications

The single test computer and operating system used for the testing had the following specifications:

Specifications: 2 processor Intel Core™2 6600 CPU at 2.4 GHz, cache size: 4096 KB
Operating system: CentOS 5 (kernel 2.6.18-8.1.8.el5) for x86_64

This computer was procured circa late 2007 to early 2008.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 40 of 343 |

5.3 Compiler and Compilation Flags

This section documents the build and compilation flags used for each library. We used the highest level of optimization recommended for each library in their included documentation, installation and build files.

Janus: `g++ -D_REENTRANT -I.. -I../Janus -fPIC -O6 -Wall -march=x86-64 -funroll-loops -finline-functions -c Janus.cpp`

qhull: `CCOPTS1 = -O2 -ansi -fno-strict-aliasing`

Xerces, version 2.8.0: as of version 2.8.0, the xerces makefile uses the -O2 optimization level for GNU/Linux with the gcc/g++ compilers.

DaveMITranslator: `-O3 -funroll-loops -finline-functions`

Simulation: `-O3 -funroll-loops -finline-functions` (affects JEOD models and sim models)

5.4 Miscellaneous Settings

Trick flags locking the CPU of the main simulation process to the second core and locking the process into memory were used. Core 0 was specified for a secondary Trick process (the Variable Server). Using these settings resulted in fewer outliers in the timing data.

5.5 Weaknesses of the Test Method


Several weaknesses are inherent in the method used to measure the duration of each model update.

These included the following:

- The measured job includes some (assumed constant) overhead needed to hook the model to the simulation:
 - Calculation of angle of attack and sideslip inputs
 - Input hookups copying data from simulation variables to Interpreter variables
 - Output hookups copying data from interpreter to simulation variables
- Only a single computer, architecture, compiler, operating system, and test case duty cycle were measured.
- The duty cycle selected, while the largest available within the capabilities of all the methods tested, does not include use of the most complicated and time consuming elements (e.g., ungridded tables). Of the four methods, only Janus has ungridded table capability.
- This restricts the test case to only the simpler constructs, severely biasing the results.

5.6 Timing Results

Figure 14 shows the raw per call processing duration results of the timing study between the four versions of the HL-20 aero model over the 400 seconds of the simulated HL-20 Auto-Landing trajectory.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | |
| | | | Page #: 41 of 343 |

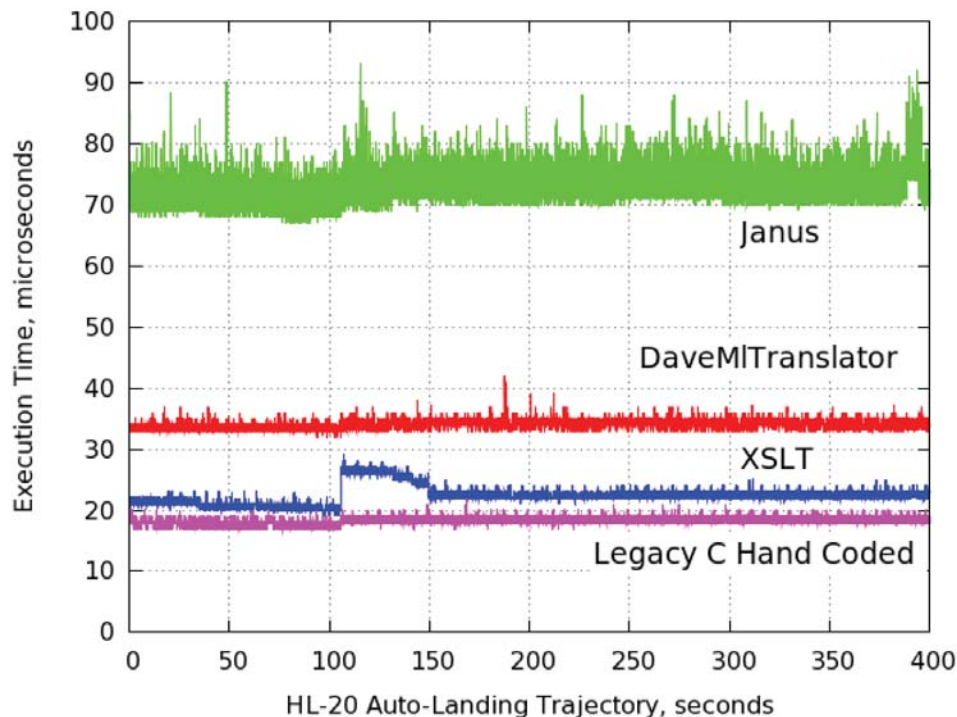



Figure 14. CPU Time per Call, HL-20 Aero Model

Only the XSLT generated code shows any marked difference in the times per call over the trajectory. The more polished algorithms show flat profiles throughout the trajectory. The reason for the jump in the XSLT call duration at 105 seconds is unknown. It doesn't seem to correlate with any event of importance, except perhaps crossing under Mach 2. (The jump occurs well before the start of turning around the Heading Alignment Cylinder.) It was originally theorized that the increased CPU time in this region was due to not-optimizing the search for the table look-up step in the independent variable which was naively repeated from the first breakpoint for each table (e.g.: 193 times per call for Mach). However, an experimental version of the simple recursive linear interpolator, which retained and re-used the solution of the most recent lookup, only improved the times for the XSLT generated model by around 2 microseconds all across the trajectory without changing the shape of the profile. Since performing an optimization study wasn't the point of the XSLT code generation feasibility exercise, further study of this interesting characteristic was not performed.

Table 3 shows a summary of the data, with overall representative time values chosen by eye.

Table 3. CPU Time per Call Summary, HL-20 Aero Model

| Aero Model | CPU Time Per Call, micro-secs |
|-----------------------|-------------------------------|
| Janus | 73 |
| DaveMITranslator | 34.5 |
| XSLT Generated C code | 22.5 - 28 |
| Legacy Hand Coded C | 18 |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 42 of 343 |

5.7 Interpretation of the Results

The CPU times required to process this fairly large aero model (240 one and two dimensional table look ups) in interpreted DAVE-ML, auto-generated C/C++ code from DAVE-ML, and in hand coded C code, were seen to be fast (under 100 microseconds), and similar (within a factor of 4) for the single test computer, operating system, and other simplistic conditions of this test.

Due to the weaknesses already described in the limited testing performed, no further general conclusions should be drawn from these results.

We feel it was valuable to have more than one interpreter available, and the prototype XSLT code generator was also quite useful to have. Overall, these methods provided a spectrum of relatively quick and simple ways to implement a DAVE-ML transferred model into a simulation facility while providing performance reasonably close to hand coded algorithms. Even should real-time requirements require a customized hand coded version of a transferred model to be constructed from the DAVE-ML data, interpreted and XSLT code generated versions of the algorithm can be used to provide valuable independent comparison checks on the resulting hand coded algorithm.

6.0 NON-AERODYNAMICS MODELS IMPLEMENTED IN DAVE-ML


Two non-aerodynamic DAVE-ML models with various special features were constructed to exercise DAVE-ML outside this sphere. These models are described in the following sections.

6.1 HL-20 RCS Algorithm

The HL-20 RCS control algorithm described by Powell(18) was implemented in DAVE-ML to investigate several interesting features of this model:

- A “pseudo-dynamic” model with 24 saved states implemented via caller storage
- Use of an XSLT script to expand “macros” collecting common sub-objects, easing MathML authoring ;
 - Lead and lag compensator digital filters: <compensatorZ> element
 - Relay blocks: <relay> element
 - Limiter block: <limiter> element

The DAVE-ML implementation of the Powell RCS algorithm (see Figure 15) follows closely the MatLab™ Simulink™ implementation provided by NASA/LaRC.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 43 of 343 |

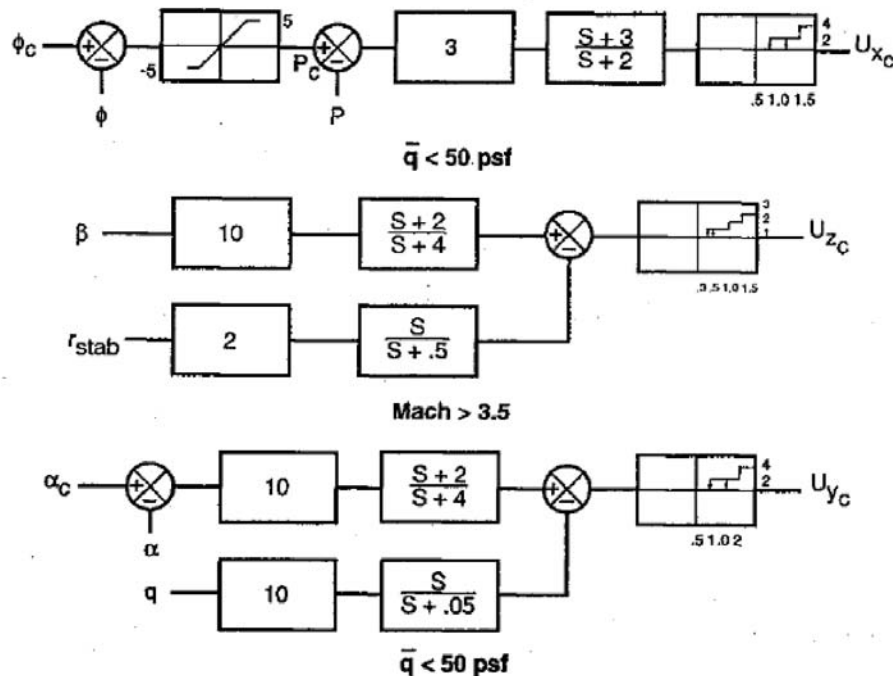


Figure 15. HL-20 RCS Algorithm of Powell(18)


The algorithm sub-objects mentioned above were implemented as “macros” allowing expansion to DAVE-ML 2.0 markup. The macros were placed in <variableDef> elements as children of <calculation> blocks. It seemed reasonable that future DAVE-ML additions would allow any such new element types to be siblings of <calculation> blocks, allowing their use in variable definitions.

Several different future forms of the compensator blocks were envisioned, e.g., S-domain and Z-domain coefficients, etc. Since DAVE-ML 2.0 compatibility was important during this investigation, the Z-domain form was chosen, sidestepping the issue of providing a menu of different discretization methods. (When directly implementing the Z domain transfer function form, only one discretization method needed to be implemented.)

The macro concept allowed the blocks to be coded in a new format, but implemented in DAVE-ML 2.0 compliant XML for use with current interpreters after expanding the macro using XSLT. (See next section.)

6.1.1 Ad hoc “Macro” Substitutions via XSLT

Implementation of this model benefited from the idea of extending DAVE-ML 2.0 through using special “macro” elements implementing algorithm sub-objects similar to MatLab™ Simulink™ “Blocks”. Future DAVE-ML versions might include specific elements for these or similar objects, using them directly. Here, XSLT was used to expand the macros to DAVE-ML 2.0 compliant form (using MathML elements) to allow the use of current DAVE-ML interpreters until such time.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 44 of 343 |

Example limiter block logic expressed in C/C++

```
// limiter element performs a two-sided limiting operation
if (input > highLimitValue) {
    output = highLimitValue;
} else {
    if (input < loLimitValue) {
        output = loLimitValue;
    } else {
        output = input;
    }
}
```

This element requires no saved states.

Example <limiter> macro element

```
<limiter inputID="limiterRollInput" loLimitValue="-5.0" hiLimitValue="5.0" />
```

Example digital compensator block logic as difference equation

A difference equation form of the digital compensator is:

$$Y_i = N_0 X_i + N_1 X_{i-1} - D_1 Y_{i-1}$$

Where:

Y = output signal
X = input signal
N = digital transfer function numerator coefficients
D = digital transfer function denominator coefficients

This element requires two saved states: X_{i-1} and Y_{i-1} .


Example <compensatorZ> macro element

```
<compensatorZ inputID="compRollInput"
    prevInputID="prev_compRollInput_input"
    prevOutputID="prev_compRollOutput_input"
    numz0="1.0" numz1="-0.9091" denz1="-0.9394" />
```

This compensator implements a digital filter with the corresponding S-domain transfer function: $\frac{(s+3)}{(s+2)}$
with the digital filter coefficients calculated via the “zero order hold” discretization method for a time step of 0.03125 seconds (32 Hz).

Example relay block logic expressed in C/C++

```
// relay element performs an input/output switch mapping with hysteresis:
if (prevOutput > loSwitchValue) {
    // was on
    if (input < loSwitchValue) {
        output = loOutputValue;
    }
}
```


| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 45 of 343 |

```

        } else {
            output = highOutputValue;
        }
    } else {
        // was off
        if (input > highSwitchValue) {
            output = highOutputValue;
        } else {
            output = loOutputValue;
        }
    }
}

```

This element requires one saved state (prevOutput).

Example <relay> macro element

```

<relay inputID="relayRollInput" prevOutputID="prev_relayRollAOutput_input"
      loSwitchValue="0.5" hiSwitchValue="1.0"
      loOutputValue="0.0" hiOutputValue="2.0" />

```


Example XSLT script to expand the <relay> element: relay.xsl

```

<?xml version="1.0" standalone="no"?>
<xsl:stylesheet version="1.0" xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
<xsl:output method="xml" encoding="iso-8859-1" indent="yes" />

<xsl:template name="relay_block">
  <xsl:comment> ===== <relay> element:
    inputID=<xsl:value-of select="@inputID"/>
    prevOutputID=<xsl:value-of select="@prevOutputID"/>
    loSwitchValue=<xsl:value-of select="@loSwitchValue"/>
    hiSwitchValue=<xsl:value-of select="@hiSwitchValue"/>
    loOutputValue=<xsl:value-of select="@loOutputValue"/>
    hiOutputValue=<xsl:value-of select="@hiOutputValue"/>
  was expanded to:
  </xsl:comment>
  <calculation>
    <math>
      <apply>
        <piecewise>
          <piece>
            <apply>
              <piecewise>
                <piece>
                  <cn><xsl:value-of select="@loOutputValue"/></cn>
                  <apply>
                    <lt/>
                    <ci><xsl:value-of select="@inputID"/></ci>
                    <cn><xsl:value-of select="@loSwitchValue"/></cn>
                  </apply>
                </piece>
              </piecewise>
            </otherwise>
            <cn><xsl:value-of select="@hiOutputValue"/></cn>
          </otherwise>
        </piecewise>
      </apply>
    </math>
  </calculation>

```


| | | | |
|---|---|--|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 46 of 343 |

```

        <apply>
        <gt;/>
        <ci><xsl:value-of select="@prevOutputID"/></ci>
        <cn><xsl:value-of select="@loSwitchValue"/></cn>
    </apply>
</piece>
<otherwise>
    <apply>
        <piecewise>
            <piece>
                <cn><xsl:value-of select="@hiOutputValue"/></cn>
                <apply>
                    <gt;/>
                    <ci><xsl:value-of select="@inputID"/></ci>
                    <cn><xsl:value-of select="@hiSwitchValue"/></cn>
                </apply>
            </piece>
            <otherwise>
                <cn><xsl:value-of select="@loOutputValue"/></cn>
            </otherwise>
        </piecewise>
    </apply>
</otherwise>
</piecewise>
</apply>
</math>
</calculation>
<xsl:comment> ===== end of expanded <math>relay</math> element </xsl:comment>

</xsl:template>
</xsl:stylesheet>

```


Example Expanded DAVE-ML 2.0 Compliant $relay$ Block

Example excerpt showing a sample DAVE-ML variableDef (variable definition) element featuring an expanded relay macro in DAVE-ML 2.0 compliant XML:

```

<variableDef name="relayRollA" varID="relayRollA" units="nd" initialValue="0.0">
  <description>Roll relay A</description>
  <!-- ===== <math>relay</math> element:
    inputID="relayRollInput"
    prevOutputID="prev_relayRollAOutput_input"
    loSwitchValue="0.5"
    hiSwitchValue="1.0"
    loOutputValue="0.0"
    hiOutputValue="2.0"
  was expanded to:
  --><calculation><math><apply><piecewise><piece><apply><piecewise><piece><cn>0.0</cn>
<apply><lt/><ci>relayRollInput</ci><cn>0.5</cn></apply></piece><otherwise><cn>2.0</cn>
</otherwise></piecewise></apply><apply><gt/><ci>prev_relayRollAOutput_input</ci>
<cn>0.5</cn></apply></piece><otherwise><apply><piecewise><piece><cn>2.0</cn><apply>
<gt/><ci>relayRollInput</ci><cn>1.0</cn></apply></piece><otherwise><cn>0.0</cn></o
therwise></piecewise></apply></otherwise></piecewise></apply></math></calculation>
  <!-- ===== end of expanded <math>relay</math> element -->
</variableDef>

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 47 of 343 |

Here, the MathML was simply expanded to one very long unreadable source line, since the purpose of the macro was to abstract and encapsulate this MathML construct. (Minor additions to the XSLT script could be made to format this in human-readable/editable form, if desired.)

6.1.2 Test Method

The HL-20 RCS algorithm was tested using a rigid body simulation featuring the DAVE-ML HL-20 aero model at low dynamic pressure (where the RCS jets can override the natural aerodynamic stability of the vehicle). The RCS thruster model used for the HL-20 was given in Reference (18) and repeated in Table 4 below.

Table 4. HL-20 RCS Thruster Model

| Axis | Moment (per thruster) | Number of Thrusters |
|-------|-----------------------|---------------------|
| Roll | 100 ft-lbf | 2 or 4 |
| Pitch | 333 ft-lbf | 2 or 4 |
| Yaw | 333 ft-lbf | 1, 2 or 3 |

The HL-20 rigid body mass model (also from(18)) is repeated in Table 5.


Table 5. HL-20 Entry Rigid Body Mass Model

| Axis | Inertia |
|-------|----------------------------|
| Roll | 7512 slug-ft ² |
| Pitch | 33594 slug-ft ² |
| Yaw | 35644 slug-ft ² |
| | Mass |
| | 19,100 pounds |

An artificial test state was constructed that reduced the dynamic pressure by a factor of 1,000. The state was otherwise correctly represented as 100,000 feet altitude and Mach 4. This adjustment was required because the DAVE-ML HL-20 aero models' range of validity extends from Mach 0.0 to only Mach 4, well below the Mach number where the low dynamic pressure region of RCS utility is usually encountered.

6.1.3 Results

The attitude performance of the algorithm in angle of attack and roll was tested using a series of ramp inputs, as shown in Figures 16, and 17. Figure 18 shows the profile of body rates resulting from thruster firings over the same time period. Because the algorithm was designed to maintain zero sideslip angle, no ramp command in yaw was used. However, yaw firings were required as seen in Figure 18 to maintain low sideslip during the combined pitch and roll maneuver of the test.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 48 of 343 |

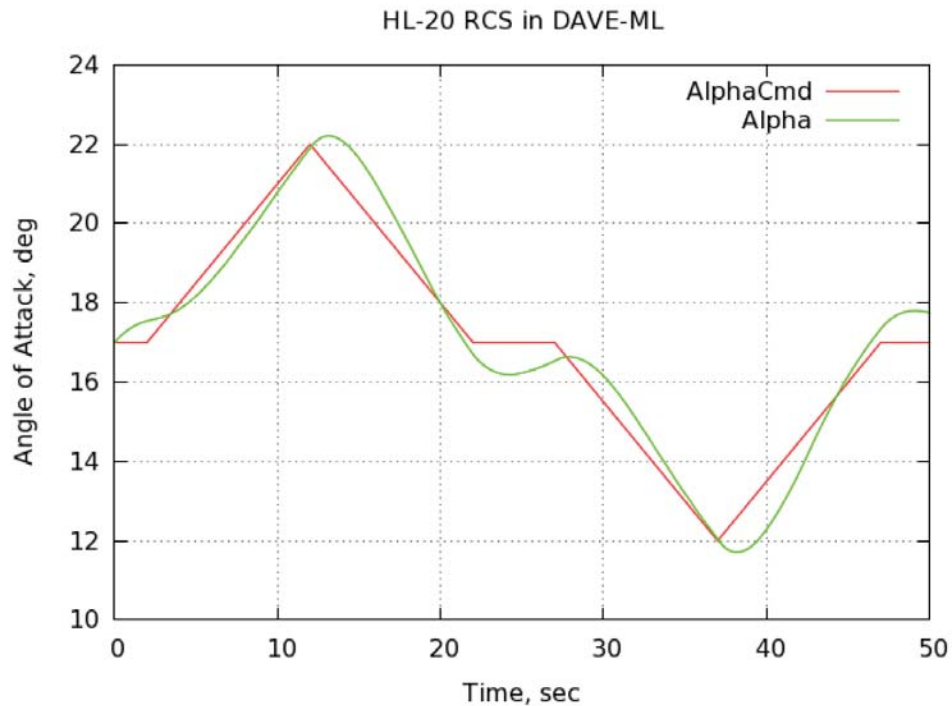



Figure 16. DAVE-ML HL-20 RCS Algorithm Test Results: Angle of Attack

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 49 of 343 |

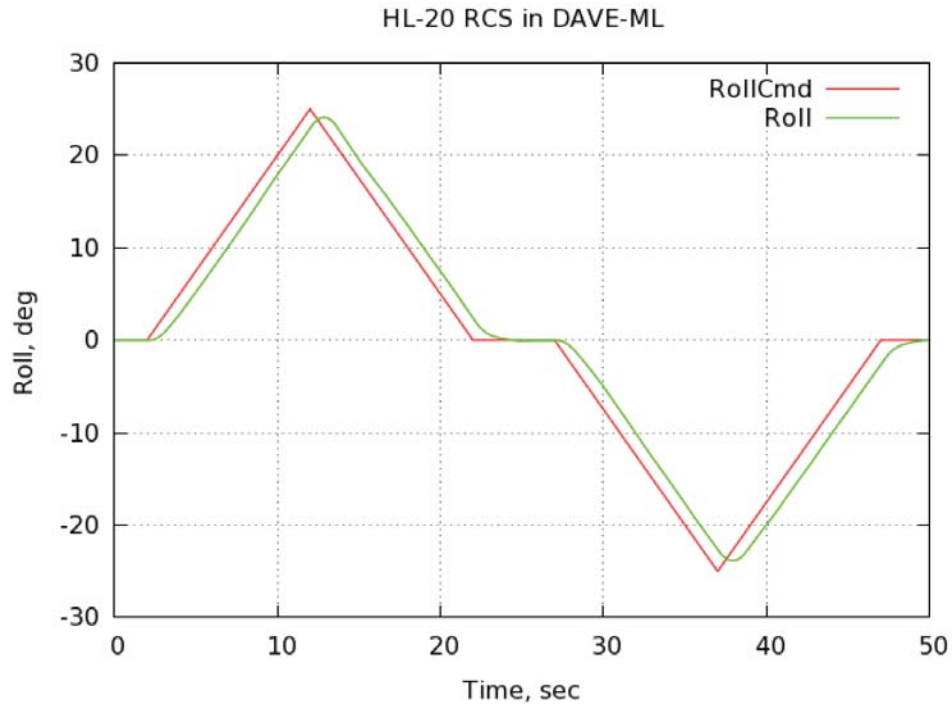



Figure 17. DAVE-ML HL-20 RCS Algorithm Test Results: Roll Angle

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 50 of 343 |

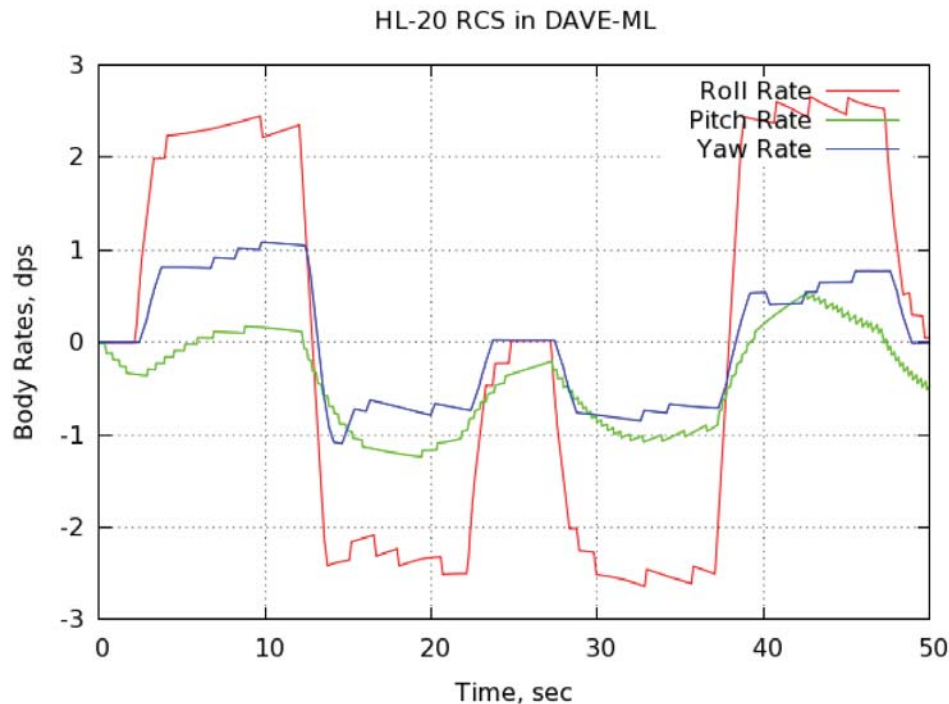



Figure 18. DAVE-ML HL-20 RCS Algorithm Test Results: Body Rates

6.1.4 Lessons Learned

Pseudo-dynamic models were constructed under the existing DAVE-ML 2.0 DTD by using the caller to store what would be internal variables in a postulated future dynamic DAVE-ML. For now, the caller sends the states in as additional inputs, accepts them back as model outputs, and re-routes the values back into the input storage for the next call. Using the TDM_Map system (discussed above in the Software Section) to hook the DAVE-ML models to the Trick simulation, we were able to use the same simulation-side variables hooked to both the DAVE-ML input and output variables, so no explicit copying from model output to input was required between calls. This made the system very convenient to use. The caller essentially just provides a work array of the proper size for the saved states and prepares the TDM_Map XML file indicating the hookup of each work array element to each DAVE-ML internal variable representing the dynamic states for both input and output.

“Macros” expanded via a capable scripting language such as XSLT can be used to considerably simplify the authoring of complex MathML constructions. This allows the model author to make useful ad hoc “additions” to DAVE-ML and then generate DAVE-ML 2.0 compliant markup on-the-fly via XSLT for use with existing interpreters and DTD. If future DAVE-ML versions implement similar blocks, the implementation will likely be much closer to the macro element form than to the DAVE-ML 2.0 MathML based expansions, so using the macro form seems likely to ease any future conversion task.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 51 of 343 |

6.2 Pneumatic Tire Data Compression Model

The Pneumatic Tire Data Compression Model is a multi-input / multi-output set of three hierarchical DAVE-ML model files that coordinate to calculate the lateral forces on a tire from a set of experimental coefficients and the current simulation states of a tire (normal force F_n , slip angle α , and inclination angle γ). A high level diagram mapping the hierarchy is shown in Figure 19.

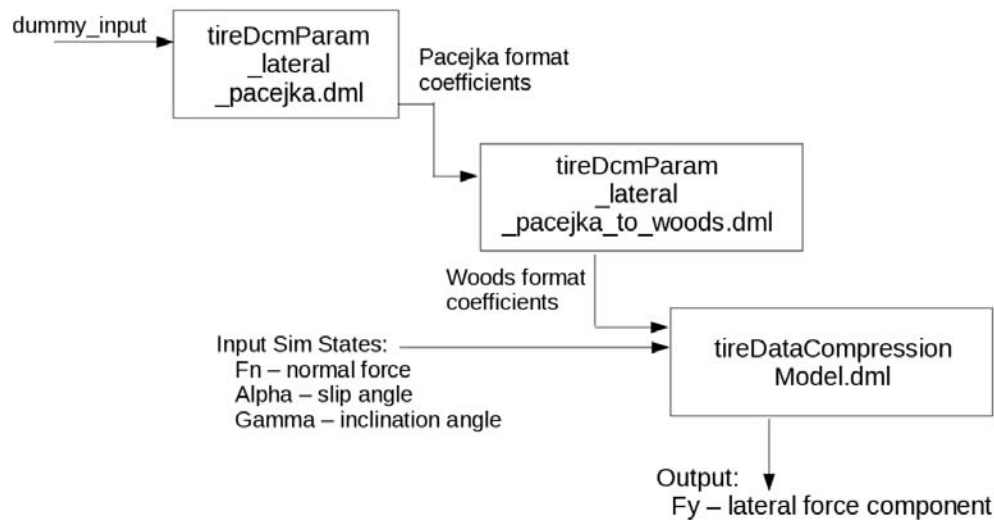



Figure 19. Tire Data Compression Model Set

This model set features:

- A zero input / multiple output model
- Hierarchical model sets where the outputs from one model are used as inputs to the next
- An “equation heavy” model: no table look ups, just equations implemented in MathML
- Use of a script to expand “macros” collecting common terms, easing MathML authoring.

A Data Compression Model, as used in the modeling of pneumatic tires for automobiles, uses a single curve fit of complex shape that can be adjusted through a set of experimentally derived and curve fit coefficients to generate tire force results over a wide range of several important input state parameter values(19). In this case, the curve fit is the “Magic Tire Formula” developed by Pacejka, as normalized by Woods(20).

The Pacejka coefficients comprising the tire lateral force model are stored in a zero input / multiple output DAVE-ML file named `tireDcmParam_lateral_pacejka.dml`. DAVE-ML is used here for its self documentation features. Unfortunately, some portions of the DAVE-ML 2.0 specification preclude the use of zero input models. (The `checkData` element, if present, requires at least one input variable as the `checkInputs` element requires at least one signal element.) A workaround to use this type of model with existing DAVE-ML 2.0 compliant interpreters is simply to provide a single unused dummy input. This output only model can be run once only, with the outputs input to the next model.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 52 of 343 |


The second model, `tireDemParam_lateral_pacejka_to_woods.dml`, converts the coefficients from Pacejka to Woods format. Woods developed a useful normalization of the Pacejka model resulting in a different coefficient set that can be used in place of the standard Pacejka coefficients, with coefficients calculable from the Pacejka coefficients. This middle model can also be run once only. It takes Pacejka format coefficients as input, with the output being the set of Woods format coefficients needed for the run-time stage. The DAVE-ML `checkData` feature is used to check the conversion using a comprehensive set of internal test case data reported by Woods.

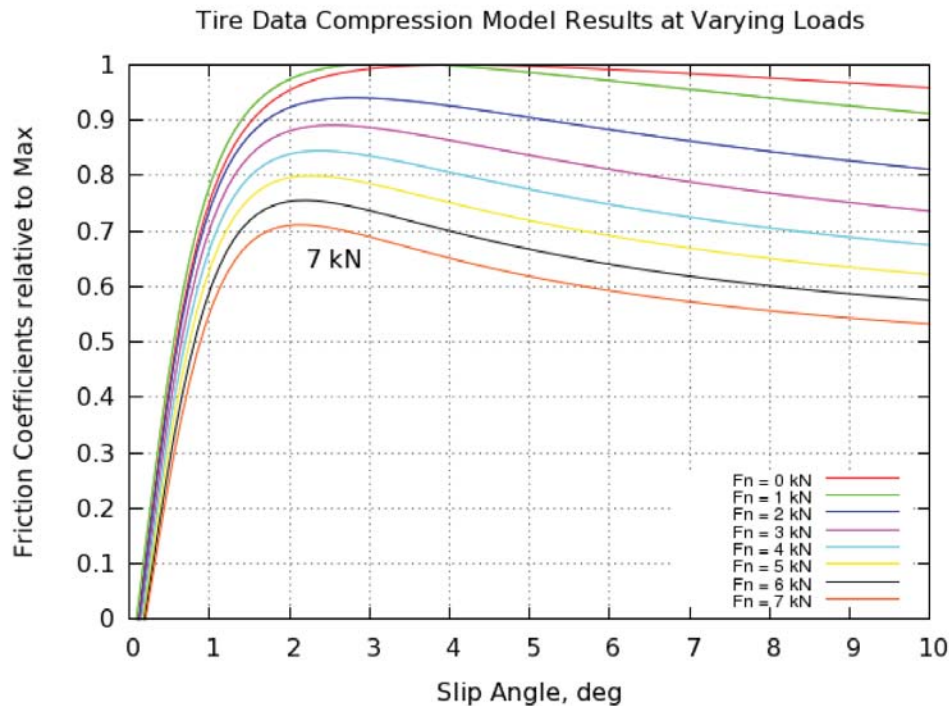
The DAVE-ML tire data compression model file `tireDataCompression.dml` makes heavy use of DAVE-ML's ability to implement algorithms through embedded MathML elements. The model contains no table look ups, only MathML equations. It calculates the output lateral force as complex functions of the coefficients and varying input states:

$$\text{tire lateral force} = f(\text{slipAngle}, \text{normalForce}, \text{inclination}, \text{coefficients})$$

Example output from the model is shown in Figure 20. The figure compares the output lateral force for several normal force load levels over a range of slip angles. The variation of the ratio of lateral force to maximum lateral force and the slip angle for peak force both vary smoothly under control of the model. The effect of the asphericity modeled in the example tire model coefficients provided by Woods (20) is evident as the friction coefficients cross zero at a small positive slip angle rather than zero. The small but non-zero offset forces programmed into the model also cause the friction coefficients to exceed the expected zero normal force maximum at low normal force levels.

The slip angle for peak friction coefficient for these tire model parameters becomes smaller as the load increases.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 53 of 343 |




6.2.1 Ad hoc “Macro” Substitutions via Script

Implementation of this model benefited from the concept of extending DAVE-ML 2.0 through the use of special “macro” elements similar to those used in the HL-20 RCS algorithm. The Woods normalized form of the Pacejka Magic Tire Formula makes repeated use of Linear Degradation and Quadratic Degradation constructs which proved straight forward to abstract out as macros. (This is the reason this form of the tire model was used.) However, for this model, XSLT was not used to expand the macros to DAVE-ML 2.0 compliant form as was done for the HL-20 RCS model. Instead, the object oriented high level (scripting) language Ruby (21) was used to expand the macros into DAVE-ML 2.0 compliant markup.

Several restrictions to the format of the macros were imposed to enable use of an extremely simple parsing system to detect and expand the macro:

- Attributes all present
- Attributes in the expected order
- Entire macro element on a single line
- No other elements allowed on the macro line

This allowed the parsing of the macro and attributes to be performed entirely within regular expression queries as the input file was processed line-by-line, greatly simplifying the script.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 54 of 343 |

Example common Quadratic Degradation term in equation form:

$$1 - 0.1 \left(\frac{\gamma}{\gamma_{y\mu}} \right)^2$$

Macro source form of the Quadratic Degradation term:

```
<quadraticDegradation constValue="1.0" gainValue="-0.1" numID="gamma" denID="gamma_y_mu"/>
```


Script output excerpt of the DAVE-ML 2.0 compliant form of the Quadratic Degradation after expansion:

```
<!-- ===== <quadraticDegradation> element:
constValue = 1.0
gainValue = -0.1
numID = gamma
denID = gamma_y_mu
was expanded to: -->
<apply>
  <plus/>
  <cn>1.0</cn>
  <apply>
    <times/>
    <cn>-0.1</cn>
    <apply>
      <power/>
      <apply>
        <divide/>
        <ci>gamma</ci>
        <ci>gamma_y_mu</ci>
      </apply>
      <cn>2</cn>
    </apply>
  </apply>
</apply>
<!-- ===== end of expanded <quadraticDegradation> element -->
```

6.2.2 Lessons Learned

Macros expanded via a capable scripting language using a simple parsing strategy can be used to considerably simplify the authoring of complex MathML constructions where repeated portions can be collected into macros. This provides a second technique alongside XSLT for expanding on-the-fly ad hoc extensions to the DAVE-ML specification.

Use of DAVE-ML for self-documenting data files is impeded by the DTD restrictions against no input models. Although a trivial workaround is available, the DAVE-ML specification could be modified to allow these sorts of models without employing the workaround of using a dummy input variable.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 55 of 343 |

7.0 DAVE-ML SPECIFICATION COMMENTS/SUGGESTIONS

7.1 Uncertainty Element

As part of our investigation of DAVE-ML, we studied the `uncertainty` XML element in the DAVE-ML specification. As a result of this study, we (1) collected some observations on the element itself and (2) wrote a proposed replacement for the section of the DAVE-ML Reference Manual that addresses uncertainty.

A draft of our proposed section to the Reference Manual is included in the appendix. It probably warrants some follow-up conversations with the community. Indeed there are places in our draft where we call out issues that we believe warrant further clarification.

Our collected observations are briefly summarized below.

The `bounds` attribute.

The current DAVE-ML DTD does not adequately constrain the `bounds` attribute in the several places where it may be used in the model XML. For example, when the `uncertainty` element is applied to a single data value, then only one numerical bound is meaningful for normally distributed uncertainties; but when the element is applied to a data table, there must be as many bounds as there are data values in the table. The DTD could be redesigned so that XML validity would help ensure that the correct number of bounds values are specified in the model. Also, the discussion of the `bounds` attribute in the reference manual is incomplete, accidentally omitting the discussion of bounds in the context of data tables. At the very least, the DTD should enforce a single bound when the `uncertainty` element is applied to a single value for normally distributed data.


The `effect` attribute.

It is our understanding that the `absolute` value of the `effect` attribute is only applicable to uniformly distributed random data. Yet the current XML design allows it for normally distributed data as well. Thus a DAVE-ML model might validate (in the sense of XML "validation") yet not make any sense. The design of the DAVE-ML XML could avoid this if the `effect` attribute were moved "down" in the XML from the `uncertainty` element to the `normalPDF` and `uniformPDF` elements. We suggest that this be done and that the DTD only allow the absolute value for the `effect` attribute when that attribute occurs in the `uniformPDF` element.

Specification semantics.

In the course of our work with the `uncertainty` element, we struggled to understand how its use in a DAVE-ML file is supposed to be interpreted -- what use cases it is intended to support. Although the intended use of the element on input data is easy to imagine (e.g., support Monte Carlo analysis), the intended use of the element applied to internal and especially to output data is unclear. In some cases, these intended uses can be clarified by additional discussion in the reference manual, but in some cases the standard does not specify unambiguous direction to simulation developers on how to interpret the `uncertainty` element.

A data interchange standard may seek to solve three different kinds of problems: (1) making the data *readable* by all parties (i.e., avoiding the problems implicit in proprietary file formats), (2) *labeling* the various data items so in addition to being able to read the file, consumers can unambiguously identify which data item is meant to serve what role in the model, and (3) defining the *semantics* of the data so that not only are all data items readable and unambiguously identified, but the consumer knows how to use them without consulting the producer of the data.

| | | | |
|---|---|--|-----------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 56 of 343 |

Simple ASCII comma separated value (CSV) files provide an example of a solution to problem #1. The data are readable by virtue of the fact that the data are in an ASCII format and are delimited by a well-defined character. However a simple CSV file does not specify which columns have what meaning.


XML files can solve problem #1 as well as problem #2. Not only are the data readable, but they are (in most cases) unambiguously identified.

We feel that there are some applications of the DAVE-ML `uncertainty` element where the intended use is not currently specified by the standard and hence cannot possibly be implemented by generic simulation frameworks. For example, what does it mean for the statistics of an *output* data value to be specified in a model? How should a DAVE-ML-compliant simulation framework process such elements? It is entirely possible that there are good answers to this problem, in which case this is just a matter of expanding the Reference Manual to clarify the intended interpretations. But if there is not universally agreed upon intended use for such cases, then the DAVE-ML community in general and the Reference Manual in particular should explicitly acknowledge that there are situations where a valid DAVE-ML model cannot be properly processed by a consumer until the engineers on the consuming side have consulted with the engineers on the producing side. It is our understanding that the motivation behind the DAVE-ML model exchange standard was to avoid the need for such consultations. Therefore we feel that the DAVE-ML community should discuss the intended semantics of the `uncertainty` element in more detail before encoding it in the standard.

7.1.1 Suggestions

Based on our study of the DAVE-ML model of uncertainty, we have the following suggestions. Some of these relate to the XML syntax (i.e., the DTD) and some relate to the DAVE-ML Language Manual.

- effect attribute
 - effect=“absolute” only applies to uniform distributions
 - suggestion: move this attribute from the uncertainty element one level down to the normalPDF and uniformPDF elements, and don’t allow effect=“absolute” in normalPDF.
- percentage vs. multiplicative effects
 - effect=“percentage” and effect=“absolute” are different ways of saying the exact same thing (except for a factor of 100). This needlessly complicates the standard.
 - suggestion: choose one and eliminate the other.
- bounds element
 - the DTD allows any number of bounds elements even in cases where only one or two are allowed.
 - suggestion: change the DTD to precisely constrain the number of occurrences of the attribute in the 1-occurrence case for normal distributions, the 2-occurrence case for uniform distributions and the N-occurrence case for data tables.
- randomizing table data
 - There is no explicit guidance given to tool developers on how uncertain data points inside data tables should be interpolated. Should the interval boundaries be interpolated first and then a random value generated based on the uncertainty specification? Or should the interval boundaries be randomized according to the uncertainty specification and then interpolated.
 - suggestion: add explicit language clarifying the intent in the Reference Manual.
- upper/lower uniform bounds in a data table
 - How should uniform distribution upper/lower bounds be encoded in a data table? For a table with N entries, there should be 2N bounds (an upper and lower bound for each table entry). The documentation in the DTD is incorrect for this case. It says that the table dimensions must match.
 - suggestion: Fix the documentation in the DTD. Clarify this point in the Reference Manual.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 57 of 343 |


- nominal values
 - The documentation in the DTD for uniformPDF incorrectly says that the nominal value is given elsewhere in the parent XML element. This is true for tables but not true in general. For example, if the signal in question is an input or output, the nominal value is not specified in the XML file at all but rather determined during simulation execution.
 - suggestion: Fix the documentation in the DTD.
- symmetric attribute
 - The Reference Manual refers to a symmetric attribute of the uniformPDF element. This is evidently an artifact of a previous version of the DTD, as the current DTD has no such attribute.
 - suggestion: Update the Reference Manual.
- comma separated data tables
 - The DTD is unable to constrain the contents of a data table to be comma delimited numerical values. This is a fundamental limitation in DTDs. XML Schema would allow the content to be constrained according to a regular expression, and XML Schema is widely used in the XML community with significant tools support available.
 - suggestion: Move the XML specification from a DTD to XML Schema.
- correlation-related attributes
 - The attributes correlatesWith and correlation (in the normalPDF element) should be mutually exclusive. Furthermore, there is no DTD-enforced constraint that both attributes be used correctly together (i.e., that the correlatesWith attribute designates a signal with a corresponding correlation attribute).
 - suggestion: Make these child elements instead of attributes. Use XML Schema to enforce mutual exclusivity. If possible use XML schema constraints to insist that an element referred to by correlatesWith actually does have a correlation.
- correlation in data tables
 - It appears that the correlatesWith and correlation attributes may only be used in “scalar” signals (not in data tables).
 - suggestion: If this is true, mention this in the Reference Manual. If it is not true, include an example of how to use correlation with data tables.

7.2 GriddedTableDef Element

A `griddedTableDef` element at the root level of a legal (according to the DTD) DAVE-ML file is not required to have a `@gtID`. This makes it impossible to guarantee that that file can be transformed to “C”. In order to make that possible, a user would currently be required to manually verify that `GriddedTablesDefs` did have `gtIDs`.

7.3 CheckData Element

The current DAVE-ML 2.0 DTD does not allow zero input (or output only) models. These can be useful to take advantage of DAVE-ML’s self documenting elements for static data files for “Initialization Load” (I-Load) type data. The `checkData/staticShot/checkInputs` hierarchy of elements requires at least one input signal definition, once the `checkData` element is present. Removing this restriction would allow zero input output-only models without use of the workaround of using a dummy input currently required by the DAVE-ML 2.0 DTD.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 58 of 343 |

8.0 CONCLUSIONS

Several comments and suggestions were developed concerning the DAVE-ML specification included within the S-119 Specification:

- Use of DAVE-ML for self-documenting data files is impeded by the DTD restrictions against no input models (checkData hierarchy). Suggest removing DAVE-ML DTD restrictions against no input models.
- Suggest requiring gID attributes for griddedTableDef elements
- Suggest revising the uncertainty element specification for greater clarity.

See the Appendix for suggested revisions, with comments describing areas where further review is suggested

“Macro” elements expanded via a capable scripting language can be used now to considerably simplify the authoring of complex MathML constructions, and possibly ease conversion to future DAVE-ML versions that implement similar features directly. XSLT or high level scripting languages can be used to transform the output to current DAVE-ML 2.0 compliant form.

General, reusable methods of hooking simulation variables to interpreted DAVE-ML model input and output variables can be created to specify the corresponding variable names conveniently via an input file.

Pseudo-dynamic models can be constructed now under the existing DAVE-ML 2.0 DTD by using a caller provided work array as additional model inputs and outputs holding what would be internal variables in a postulated future dynamic DAVE-ML. A sim-variable-to-DAVE-ML-model-variable hookup system, similar to the described TDM_Map system, can do this transparently to the user by hooking the model outputs back into the inputs by specifying the hookups via an input file that calls out the same sim variables for both input and output.


Reasonably efficient C language source code can be automatically generated from DAVE-ML via XSLT, at least for the simpler constructs. Although incomplete, the system prototyped during this project is useful now and shows considerable potential.

We feel it was valuable to have more than one interpreter available, and the prototype XSLT code generator was also quite useful to have. Overall, these methods provided a spectrum of relatively quick and simple ways to implement a DAVE-ML transferred model into a simulation facility while providing performance reasonably close to hand coded algorithms. Even should real-time requirements require a customized hand coded version of a transferred model to be constructed from the DAVE-ML data, interpreted and XSLT code generated versions of the algorithm can be used to provide valuable independent checks on the resulting hand coded algorithm.


9.0 FUTURE WORK

We have identified several potential follow-on work topics. These are:

- Further review of the S-119/DAVE-ML specifications
- Exercise an expected revision greatly expanding the HL-20 aero model
 - Even larger model
 - Possibly exercising a wider subset of DAVE-ML features


| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 59 of 343 |

-
- Continue development of the XSLT DAVE-ML to C code generator
 - Increase its coverage of DAVE-ML constructs,
 - Increase robustness for production work
 - Low barrier-to-entry code generation from DAVE-ML may assist adoption of the standard
 - Integrate DAVE-ML model uncertainty into the Trick Simulation Environment
 - Exercise with Monte-Carlo test cases.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 60 of 343 |

10.0 BIBLIOGRAPHY

1. *Flight Dynamics Model Exchange Standard*. s.l. : American Institute of Aeronautics and Astronautics, 200X. BSR/AIAA S-119-200X, (DRAFT).
2. **Jackson, E. Bruce**. *Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML) Reference, Version 2.0 (RC3)*. s.l. : AIAA Modeling and Simulation Technical Committee, 2010.
3. *The DaveMLTranslator: An Interface for DAVE-ML Aerodynamic Models*. **Hill, Melissa A. and Jackson, E. Bruce**. s.l. : American Institute of Aeronautics and Astronautics, 2007. AIAA Modeling and Simulation Technologies Conference and Exhibit.
4. *The Jamus C++ Library - An Interface Class for DAVE-ML Compliant XML-Based Flight Model Datasets*. s.l. : Defense Science and Technology Organization, 2010. 0708-232.001, version 1.10.
5. **W3C**. XSL Transformations (XSLT) Version 2.0. *World Wide Web Consortium Web Site*. [Online] 2007. <http://www.w3.org/TR/xslt20>.
6. **Tidwell, D.** *XSLT: Mastering XML Transformations, Second Edition*. s.l. : O'Reilly Media Inc.
7. *Trick User's Guide*. NASA Johnson Space Center : National Aeronautics and Space Administration, 2010.
8. *JSC Engineering Orbital Dynamics (JEOD) Top Level Document*. NASA Johnson Space Center : National Aeronautics and Space Administration, 2009. JSC-61777-docs.
9. Reference Manual for libxml2. [Online] <http://xmlsoft.org/html/index.html>.
10. **Apache.org**. Xerces-C++ XML Parser. [Online] <http://xerces.apache.org/xerces-c/api-2.html>.
11. Qhull, code for convex hull, Delaunay triangulation, Voronoi diagram... [Online] <http://www.qhull.org/>.
12. **Object Modeling Group**. Unified Modeling Language™ (UML(R)), version 2. [Online] 2005.
13. **Gamma, et al.** *Design Patterns, Elements of Reusable Object-Oriented Software*. Reading, MA : Addison-Wesley, 1994.
14. **W3C**. Mathematical Markup Language (MathML) Version 2.0 (Second Edition). [Online] 2003. <http://www.w3.org/TR/MathML2>.
15. —. Extensible Markup Language (XML) 1.1 (Second Edition). *World Wide Web Consortium Web Site*. [Online] 2006. <http://www.w3.org/TR/2006/REV-xml11-20060816/>.
16. **Jackson, E. Bruce and Cruz, Christopher I.** *Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body*. NASA Langley Research Center : National Aeronautics and Space Administration, 1992. Technical Memorandum 4302.
17. —. *Real-Time Simulation Model of the HL-20 Lifting Body*. NASA Langley Research Center : National Aeronautics and Space Administration, 1992. Technical Memorandum 107580.
18. *Six Degree-of-Freedom Guidance and Control Entry Analysis of the HL-20*. **Powell, R.W.** 1993, Journal of Spacecraft and Rockets, Vol.30, No.5.
19. **Milliken, W.F. and Milliken, R.L.** *Race Car Vehicle Dynamics*. s.l. : SAE, 1997.
20. *Normalization of the Pacejka Tire Model*. **R.L.Woods**. s.l. : SAE, 2004. SAE 2004-01-3528.
21. Ruby object-oriented scripting language. [Online] <http://www.ruby-lang.org/en/>.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 61 of 343 |

APPENDIX A Draft DAVE-ML Uncertainty Reference

It is our feeling that a more extensive discussion of the `uncertainty` element in the DAVE-ML Language Reference would help clarify its intended use and thus help software developers write interoperable DAVE-ML processing code. This appendix is a draft of a proposed replacement for Section 6.4 (Statistics) section of the language reference, which we propose be renamed “Uncertainty”. It is undoubtedly incomplete but nevertheless captures our thoughts on what kind of discussion is warranted.

In some places we have inserted “Author’s comments” where our understanding of the proposed XML syntax is incomplete. Additionally, please note that the section numbers in this appendix do not pertain to this document – they are actually the relevant section numbers from the DAVE-ML Language Reference.

6.4 Uncertainty

6.4.1 Introduction

6.4.1.1 Motivation

DAVE-ML supports the specification of statistical uncertainty using the `uncertainty` element. Its purpose is to allow models to characterize model uncertainty in two primary use cases.

Use Case 1. Support Monte-Carlo simulation by allowing statistical variation of parameter values. DAVE-ML supports specification of the uncertainty associated with constant parameters in addition to the nominal value of the parameter itself. Thus DAVE-ML compliant simulations may run multiple versions of a particular scenario, each with different parameter values within the statistical bounds specified by the associated `uncertainty` element associated with each parameter.

Use Case 2. Support Monte-Carlo simulation by allowing statistical variation of table lookup values. DAVE-ML supports this use case with the specification of uncertainties of dependent values whose nominal values are defined in gridded or ungridded tables. Thus DAVE-ML compliant simulations may run multiple versions of a particular scenario, each with different values of the lookup data within the statistical bounds specified in the tables.


In addition, DAVE-ML also allows the specification of uncertainties associated with *any signal* in a model, including inputs, outputs or intermediate values. This capability is included as a “catch all” for model developers whose use cases do not fall into the two mentioned above. In these cases, DAVE-ML-compliant software tools should substitute appropriately generated random values according to the semantics described below at the specified locations.

6.4.1.2 Approach

The DAVE-ML approach to statistical uncertainty is the `uncertainty` element which may be inserted in a model wherever the signals should have a statistical distribution about some nominal value. In particular, the `uncertainty` element may be a sub-element of the `variableDef`, `griddedTableDef` and `ungriddedTableDef` elements.

Of course, DAVE-ML models only specify the statistical properties, not the random values themselves. It is up to DAVE-ML-compliant software tools to generate appropriately randomized data according to the specifications in the `uncertainty` element. Likewise it is up to the frameworks to seed the random number generators in some problem-appropriate fashion.¹

¹ For example, if the particular simulation run must be repeatable (albeit with randomized variable values), then the random number generator must be seeded from a deterministic value. Such seeding is beyond the scope of the DAVE-ML standard.

| | | | |
|---|--|--|---|
|  | <div>NASA Engineering and Safety Center</div> <div>Technical Assessment Report</div> | <div>Document #:</div> <div>NESC-RP-09-00598</div> | <div>Version:</div> <div>1.0</div> |
| <div>Title:</div> <div>Flight Simulation Model Exchange</div> | | | <div>Page #:</div> <div>62 of 343</div> |

The following sections summarize the syntax and semantics of the `uncertainty` element and present some examples of its use.

6.4.2 Syntax

DAVE-ML supports specification uncertainties distributed *normally* or *uniformly* about nominal values. (These are the only possible distributions.) Which of these is used depends on the content of the `uncertainty` element, in particular whether the `uniformPDF` or `normalPDF` sub-elements are present. Both of these elements in turn characterize their distribution using several attributes and elements (described below). The most important of these is the `bounds` element which specifies the numerical characteristics of the uniform or normal distribution.

6.4.2.1 The `bounds` element

At root, this element is just a scalar numerical value. For example, it could be the upper or lower bound of a uniform distribution, or it could quantify the 3-sigma value for a normal distribution. However, DAVE-ML uncertainties may also be applied to data tables in which case there must be scalar values specified for each table entry.

As a result, the form of a `bounds` element depends on the context in which it occurs. When used in scalar contexts, it contains a single scalar value. When applied to tables, it contains a `dataTable` sub-element which itself contains the several bounds values the correspond to the data table values.

Accordingly, a scalar use of the `bounds` element might appear as follows.

```
<bounds>
  100.0
</bounds>
```

And its use inside a three-element gridded or ungridded table might appear as follows.

```
<bounds>
  <dataTable>
    100.0, 200.0, 300.0
  </dataTable>
</bounds>
```

Note: The current DAVE-ML DTD does not enforce this proper use of bounds elements. It is possible for a DAVE-ML file to validate (in the XML sense) but have incorrectly specified bounds (e.g., specify a table of bounds in a scalar context).

Author's note: This description is incomplete. We have left off the use of `variableDef` and `variableRef` sub-elements. We do not understand these.


6.4.2.2 Uniform Distributions

The DAVE-ML syntax for uniformly distributed uncertainties has the following general form.

```
<uncertainty>
  <uniformPDF effect="...">
    <bounds>...</bounds>
    <bounds>...</bounds> <!-- optional -->
  </uniformPDF>
</uncertainty>
```

The `effect` attribute may be one of the following: `additive`, `multiplicative` or `absolute`.

Author's note: Our understanding of the multiplicative effect is that it is redundant with the percentage effect.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 63 of 343 |

Accordingly, we recommend that one or the other be dropped from the DAVE-ML DTD. Our description here reflects that. If we misunderstand the intent of these two effects, or if the DAVE-ML community disagrees with our preference to avoid such duplication, this description must be fixed.

The `bounds` sub-elements specify the bounds of the interval from which the uniformly distributed random values are chosen. For symmetric distributions only one bound is needed. Asymmetric distributions require two. Thus the second `bounds` sub-element is optional, but at least one must be specified.

The specific meaning of the `effect` attribute and `bounds` element are explained in the semantics section below.

6.4.2.3 Normal Distributions

The XML syntax for normally distributed uncertainties has the following general form.

```
<uncertainty>
  <normalPDF effect="..." numSigmas="...">
    <bounds>...</bounds>
    <correlatesWith varID="..." />
    <correlation varID="..." corrCoef="..." />
  </normalPDF>
</uncertainty>
```

The `effect` attribute may be one of the following: additive, or multiplicative. The `numSigmas` attribute may have the value of 1, 2 or 3. There must be one (and only one) `bounds` sub-element. And there may be zero or more `correlatesWith` or `correlation` sub-elements.

The values of the `varID` attributes of the `correlatesWith` or `correlation` sub-elements are references to other signals which must be defined in the model, and the value of the `corrCoef` attribute is a numerical value.

Author's note: See the note above regarding multiplicative and percentage effects.


The specific meaning of these attributes and elements are explained in the semantics section below.

6.4.3 Semantics

The `uncertainty` element specifies statistical characteristics associated with uncertainties about certain *nominal values*. These nominal values might be explicitly defined constant parameter values, tabulated data specified in gridded and ungridded tables or implicit (input, output or intermediate) signals calculated during the execution of a DAVE-ML tool. The distribution characteristics (e.g., mean, standard deviation, upper/lower bounds) are based on the following three numerical values: a *bound*, the *nominal value* and (for normal distributions) the *numSigmas value*.

A bound is specified in `bounds` elements². The nominal value is in general only known at runtime when the model is being executed (although for constant parameters, it is also specified in the DAVE-ML file). The `numSigmas` value is only relevant to normal distributions and is specified in the `numSigmas` attribute of the `normalPDF` element.

² In the simple case, the `bounds` element contains the numerical bound. However, the situation is more complex for tabulated. See below for a discussion for how to determine the bound in the context of data tables.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 64 of 343 |

6.4.3.1 Uniform distributions

The use of the `uniformPDF` element inside an `uncertainty` element indicates that the corresponding signal should be distributed uniformly in some interval about the nominal value. The interval may be symmetrically or asymmetrically oriented relative to the nominal value. The content of the `uniformPDF` element is used to specify the distribution interval.

DAVE-ML-compliant software must randomize the signal in question differently depending on the value the `effect` attribute. The following table summarizes how the software must calculate the randomized signal in each of the three allowable cases.

| <i>value of the effect attribute</i> | <i>description</i> |
|--------------------------------------|---|
| additive | The desired signal is the sum of the nominal value and a uniformly distributed random value. |
| multiplicative | The desired signal is the product of sum of the nominal value and the product of a uniformly distributed random value time the nominal value. |
| absolute | The desired signal is a random value uniformly distributed in some interval. (The nominal value of the signal is irrelevant in this case.) |

For uniformly distributed random values, the relevant distribution characteristics are the *upper* and *lower* bounds on the interval from which the random values are drawn. In DAVE-ML, uniform distributions are parameterized by one or two `bounds` sub-elements in the `uniformPDF` element. When two sub-elements are present, let the greater and lesser of these be called *big* and *little*, respectively. When only one sub-element is present, let *big* and *little* both be that same value. The method of determining both bounds depends on the value of the `effect` attribute as explained in the following table. (All calculations are assumed to be floating point.)


DAVE-ML-compliant software will randomize the signal in question differently depending on the value the `effect` attribute. The following table summarizes how the software must calculate the randomized signal in each of the three allowable cases.

| <i>value of the effect attribute</i> | <i>upper/lower bounds of the interval</i> |
|--------------------------------------|---|
| additive | upper = nominalValue + big lower = nominalValue - little |
| multiplicative | upper = nominalValue * big lower = nominalValue * little |
| absolute | upper = big lower = little |

6.4.3.2 Normal distributions

The use of the `normalPDF` element inside an `uncertainty` element indicates that the corresponding signal should be distributed normally about the nominal value. The content of this element is used to specify the standard deviation of the distribution around the nominal value.

DAVE-ML-compliant software will randomize the signal in question differently depending on the value the `effect` attribute. The following table summarizes how the software must calculate the randomized signal in each of the three allowable cases.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 65 of 343 |

| value of the effect attribute | description |
|-------------------------------|--|
| additive | The desired signal is the sum of the nominal value and a normally distributed random value. |
| multiplicative | The desired signal is the product of sum of the nominal value and the product of a normally distributed random value time the nominal value. |

For normally distributed random values, the relevant distribution characteristics are the *mean* and *standard deviation*. In DAVE-ML, the mean is always equal to the nominal value. The method of determining the standard deviation depends on the value of the *effect* attribute as explained in the following table. (All calculations are assumed to be floating point.)


| value of the effect attribute | standard deviation |
|-------------------------------|--|
| additive | $\text{stddev} = \text{bound} / \text{numSigmas}$ |
| multiplicative | $\text{stddev} = ((\text{bound}-1) * \text{nominal-value}) / \text{numSigmas}$ |

6.4.3.3 Tables of bounds

Author's note: A description of how the DAVE-ML-compliant software is to determine the appropriate bounds values in the context of tables is needed. The algorithms above are not sufficient. There is ambiguity in the case of tables, because it is unclear whether the algorithms are applied before or after interpolation. To clarify, if the algorithms were applied before interpolation, then a random value would be generated at each table data point, and the desired data value would be the result of interpolation between those two random values. On the other hand, if the algorithms were applied after interpolation, then the bounds values themselves would first be interpolated to give corresponding bounds values in between the endpoints, and from that value the algorithms would be used to generate a randomized value. In general, these two approaches will yield different results, and it is not clear which is intended by the DAVE-ML standard. It is very important (for interoperability) that this be specified unambiguously. This section is where we should put an description of the intended approach.

6.4.4 Examples

Author's note: We have not explicitly inserted examples here. Our intent is that the examples from the current Language Reference would fit perfectly here.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 66 of 343 |

Appendix B. American National Standard: Flight Dynamics Model Exchange Standard (draft BSR/AIAA S-119-201x)

Permission granted on April 6, 2011:

AIAA grants you permission to publish the draft of S-119 in your NASA report as an appendix.

Michael Baden-Campbell

AIAA Publications

**BSR/AIAA
S-119-201X**

American National Standard

Flight Dynamics Model Exchange Standard

Draft 2010-04-23

Sponsored by


American Institute of Aeronautics and Astronautics

Approved **XX Month 201X**

American National Standards Institute

Abstract

This is a standard for the interchange of simulation modeling data between facilities. The initial objective is to allow easy, straightforward exchanges of simulation model information and data between facilities. The standard applies to virtually any vehicle model (ground, air or space), but most directly applies to aircraft and missiles.

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 67 of 343 |


LIBRARY OF CONGRESS CATALOGING DATA WILL BE ADDED HERE BY AIAA STAFF

Published by
American Institute of Aeronautics and Astronautics
1801 Alexander Bell Drive, Reston, VA 20191

Copyright © 201X American Institute of Aeronautics and
Astronautics
All rights reserved


No part of this publication may be reproduced in any form, in an electronic retrieval system
or otherwise, without prior written permission of the publisher.

Printed in the United States of America


| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 68 of 343 |

Contents

| | |
|---|-----|
| Contents..... | iii |
| Foreword..... | iv |
| Introduction..... | v |
| Trademarks..... | vii |
| 1 Scope..... | 1 |
| 2 Tailoring..... | 1 |
| 2.1 Partial Use of the Standard..... | 1 |
| 2.2 New and Reused Software Tailoring Guidance..... | 2 |
| 2.3 Creating New Variable Names and Coordinate Systems..... | 3 |
| 3 Applicable Documents..... | 3 |
| 4 Vocabulary..... | 3 |
| 4.1 Acronyms and Abbreviated Terms..... | 3 |
| 4.2 Terms and Definitions..... | 4 |
| 5 Standard Simulation Coordinate Systems..... | 6 |
| 5.1 Background / Philosophy..... | 6 |
| 5.2 Summary..... | 12 |
| 5.3 References..... | 12 |
| 6 Standard Simulation Variables..... | 12 |
| 6.1 Background / Philosophy..... | 12 |
| 6.2 Variable Naming Convention..... | 13 |
| 6.3 Variable Name Creation Methodology..... | 13 |
| 6.4 Additional Discussion..... | 25 |
| 6.5 Standard Variable Name Table Example..... | 26 |
| 6.6 Summary..... | 27 |
| 6.7 References..... | 27 |
| 7 Standard Simulation Function Table Data Format and XML Implementation of the Standard: DAVE-ML..... | 27 |
| 7.1 Purpose..... | 27 |
| 7.2 Philosophy..... | 27 |
| 7.3 Design Objective..... | 28 |
| 7.4 Standard Function Table Data — An Illustrative Example..... | 28 |
| 7.5 DAVE-ML Major Elements (reference Annex B)..... | 30 |
| 7.6 A Simple DAVE-ML Examples..... | 31 |
| 7.7 Summary..... | 38 |
| 8 Future Work..... | 38 |
| 8.1 Time History Information..... | 38 |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 69 of 343 |

| | | |
|-----|---|----|
| 8.2 | Dynamic Element Specification | 39 |
| 9 | Conclusion | 39 |
| | Annex A Standard Variable Names (Normative) | 40 |
| | Annex B Dynamics Aerospace Vehicle Exchange Markup Language (DAVE-ML) Reference (Normative) | 16 |
| | Annex C DAVE-ML Website (Informative) | 17 |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 70 of 343 |

Foreword

This standard was sponsored and developed by the AIAA Modeling and Simulation Committee on Standards. Mr. Bruce Jackson of NASA Langley conceived Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML). DAVE-ML is the embodiment of the standard in XML. The DAVE-ML reference document, including examples of its use, and the document type definition for the XML implementation are included in this standard (Annex B).

This implementation was then tested by trial exchange of simulation models between NASA Langley Research Center (Mr. Bruce Jackson), NASA Ames Research Center (Mr. Thomas Alderete and Mr. Bill Cleveland), and the Naval Air Systems Command (Mr. William McNamara and Mr. Brent York). Numerous improvements to the standard resulted from this testing.


At the time of approval, the members of the AIAA **Modeling and Simulation CoS** were:

| | |
|-----------------------|---|
| Bruce Hildreth, Chair | Science Applications International Corporation (SAIC) |
| Bruce Jackson | NASA Langley Research Center |
| Michael Madden | NASA Langley Research Center |
| Geoff Brian | Defence Science and Technology Organisation (DSTO) |
| Brent York | Indra Systems, Inc. |
| Michael Silvestro | Charles Stark Draper Laboratory, Inc. |
| Victoria Chung | NASA Langley Research Center |
| Bimal Aponso | NASA Ames Research Center |
| Jean Slane | Engineering Systems Inc. |
| Peter Grant | University of Toronto |
| William Bezdek | Boeing Phantom Works |
| Jon Berndt | Jacobs |

The above consensus body approved this document in **Month 200X**.

The AIAA Standards Executive Council (**VP-Standards Name**, Chairman) accepted the document for publication in **Month 201X**.

The AIAA Standards Procedures dictates that all approved Standards, Recommended Practices, and Guides are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any AIAA standards publication and no commitment to conform to or be guided by standards reports. In formulating, revising, and approving standards publications, the committees on standards will not consider patents that may apply to the subject matter. Prospective users of the publications are responsible for protecting themselves against liability for infringement of patents or copyright or both.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 71 of 343 |

Introduction

The purpose of this standard is to clearly define the information and format required to exchange air vehicle simulation models between simulation facilities (see Figure 1). This standard simulation interchange format is implemented in XML and is described fully in Annex B of this document.

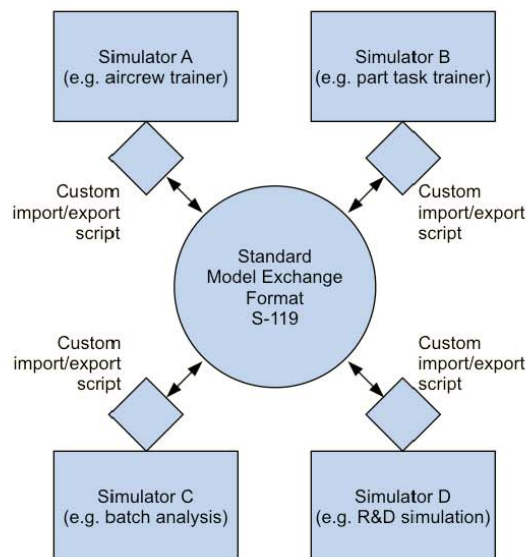



Figure 1 — Model exchange via a standardized format

The standard interchange format includes:

- Standard variable name definitions — to facilitate the transfer of information by using these standard variables as a “common language.” The interchange format can be used without using standard variable names. However, it will be more difficult because the exported model will have to include explicit definitions of all variables instead of just a subset unique to the particular model.
- Standard function table definition — to allow easy transfer of non-linear function tables of arbitrary dimension.
- Standard coordinate system and reference frame definitions — used by the variable names and function tables to clearly define the information being exchanged.
- Standard static math equation representation — for definition of static equations forming part of aerodynamic, propulsive or other models.

A specialized grammar of XML provides a format for the exchange of this information, therefore each organization is required to design import/export tools that comply with the standard one time only.

Use of this standard will result in substantially reduced cost and time necessary to exchange aerospace simulations and model information. Test cases have indicated an order of magnitude reduction in effort to exchange simple models when utilizing this standard. Even greater benefits could be attained for large or complicated models.


| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 72 of 343 |

Trademarks

The following commercial products that require trademark designation are mentioned in this document. This information is given for the convenience of users of this document and does not constitute an endorsement. Equivalent products may be used if they can be shown to lead to the same results.

Simulink ®

MATLAB®


| | | | |
|---|---|---|---------------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 73 of 343 |

1 Scope

This standard establishes definitions of the information and format used to exchange air vehicle simulations and validation data between disparate simulation facilities. This standard is not meant to require facilities to change their internal formats or standards. With the concept of an exchange standard, facilities are free to retain their well-known and trusted simulation hardware and software infrastructures. The model is exchanged through the standard, so each facility only needs to create import/export tools to the standard once. These tools can then be used to exchange models with any facility at minimal effort, rather than creating unique import/export tools for every exchange.

The standard includes a detailed convention for representing simulation variables. The purpose of this is to unambiguously describe all variables within the model when it is exchanged between two simulation customers or facilities. The variable representation includes explicit specification of all coordinate systems, units, and sign conventions used. XML is used as the mechanism to facilitate automation of the exchange of the information. Based on the definitions in the standard, a list of recommended but non-obligatory simulation variable names is included in Annex A. This list of standard variable names should further simplify the exchange of information, but is not required for use of the standard.

The standard includes capabilities for a model to be self-validating and self-documenting, with the provenance of a model's components included within the model and transferred with it. Statistical descriptions of the quality of a model may also be included.

| | | | |
|---|---|--|-----------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 74 of 343 |

2 Tailoring

The requirements defined in this standard may be tailored to match the actual requirements of any particular program or project. Tailoring of requirements should be undertaken in consultation with the procuring authority where applicable.

NOTE Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

The following sections provide further guidance on specific tailoring situations.

2.1 Partial Use of the Standard

2.1.1 General

Not all aspects of this standard may be applicable to all models or simulation applications. The following guidelines are provided to encourage appropriate use of the standard in a number of example situations.

2.1.2 Creating a New Simulation Environment

This situation calls for use of the complete standard. It is hoped that the team developing the new simulation environment would, if necessary, add to the list of standard variables and coordinate systems.

2.1.3 Creating a New Simulation Model in an Existing Simulation Environment

This situation is defined as creating a new system model (aircraft dynamic model for example) that will run in an existing simulation environment. It is expected that this is the most commonly performed work that will see benefit by application of this standard.

In this case the following tailoring guidelines are applicable.


- Apply the standard to the new development aspects of the project and all the function tables.
- Assuming that most or all of the standard variable names and coordinate systems are applicable to the simulation, use them for the new code developed for the simulation.
- In the existing simulation environment that is being reused, for example the equations of motion, there is no need to rewrite the code to use the standard variable names or coordinate systems. However, in most cases the coordinate systems used in existing simulation environments will be covered in the standard coordinate system definitions herein (Section 5). Therefore the standard coordinate systems can easily be referenced when documenting the simulation and interfaces between the new simulation components and those reused.

2.1.4 Creating or Updating a Simulation with a Long Life Expectancy

A pilot training simulator is an excellent example of this type of simulation. This simulation may only be updated every 3-10 years, so at first glance the standard may seem to be less applicable.

In fact the opposite is true. It is because of the infrequent maintenance that application of the standard is critical. In this case, in each new software update, the original developers (or previous updaters) are probably no longer available, and the update is being performed by different personnel. Software developed using the standard should be easier for the new software team to understand. They are working with clear variable definitions with which they are familiar. The function table format is understood and the functions themselves are better documented. The coordinate system definitions are clear. Changes are recorded for the benefit of any future software update.

In simulations with a long expected life, use of the state, state derivative control and output conventions as part of the variable naming convention becomes critical as these variables form the core of the model

| | | | |
|---|---|--|-----------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 75 of 343 |

and the significant inputs. It is important that the personnel modifying the simulation are able to easily identify the states, state derivatives and controls.

2.2 Implementing the Standard in a non-flat or non-scalar namespace

The variable naming convention defined within the standard makes no assumption as to the hierarchy of data components, such as object-oriented model implementation or multi-dimensional storage of matrices and vectors. The standard can accommodate these implementations through the use of a period (.) inserted before the optional domain name (e.g. `aero.bodyForceCoefficient_X`) or through the use of an appropriate indexing mechanism for the chosen implementation language (e.g. `aerobodyForceCoefficient[0]` or `aerobodyForceCoefficient(1)`). However, it should not be expected that other members of the simulation community maintain implementation-specific conventions. Therefore, on export these variable constructs should be converted to the flat, scalar namespace defined herein.

2.3 New and Reused Software Tailoring Guidance

The longer the expected life of the simulation, the more helpful the application of the standard becomes. The above tailoring guidelines may be categorized into two common situations; new and reused code.

New simulation code should

- use coordinate system definitions (Section 5) that coincide with the definitions in the standard;
- use standard variable names (Section 6) to facilitate consistency and simplify documentation requirements;
- apply the convention for states, state derivatives and controls wherever possible; and
- use standard function tables (Section 7) for all function tables.


NOTE This facilitates consistency in the data, the documentation of the data, and collaboration with other organizations to improve or debug the data.

Reused simulation code should reference the standard only when convenient to document interfaces with new code.

2.4 Creating New Variable Names and Coordinate Systems

The standard variable names and coordinate system definitions are included in the standard to facilitate communication. They provide a "common language" for the exchange. For example, it is not enough to exchange the values of the lift coefficient function. As a minimum, the independent variables used to define the function and their units, sign convention, and reference coordinate system must be defined. This need to precisely define variables is facilitated by having standard variable names and coordinate systems. Of course, new variable names, definitions, and other convenient coordinate systems may be used to exchange models between simulation facilities. However, in such cases, the exporters and importers must carefully define these variables and coordinate systems, or the exchanged model may not produce the desired results. Use of standard variable names and coordinate systems facilitates the exchange.


This standard includes a methodology for creating new standard variables. Its use is encouraged. Annex C provides the URL for submitting additional standard variable names and coordinate systems or comments on existing standard variable names and coordinate systems.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 76 of 343 |

3 Applicable Documents

The following documents contain provisions which, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

| | |
|------------------|---|
| AIAA R-004-1992 | <i>Atmospheric and Space Flight Vehicle Coordinate Systems</i> |
| IST-CR-90-50 | <i>Distributed Interactive Simulation</i> (DIS Application Protocols, Version 2, March 1994) |
| www.w3.org/XML | <i>Extensible Markup Language (XML) 1.0 (Fifth Edition)</i> , 2008-11-26 |
| www.w3.org/Math | <i>Mathematical Markup Language (MathML) Version 2.0 (Second Edition)</i> , 2003-10-21 |
| ISO 19111:2007 | <i>Geographic information – Spatial referencing by coordinates</i> |
| ISO 1151-1:1988 | <i>Flight dynamics – Concepts, quantities, and symbols – Part 1: Aircraft motion relative to the air</i> |
| ISO 1151-2:1985 | <i>Flight dynamics – Concepts, quantities, and symbols – Part 2: Motions of the aircraft and the atmosphere relative to the Earth</i> |
| ISO 1151-3:1989 | <i>Flight dynamics – Concepts, quantities, and symbols – Part 3: Derivatives of forces, moments and their coefficients</i> |
| ISO 1151-4:1994 | <i>Flight dynamics – Concepts, quantities, and symbols – Part 4: Concepts, quantities and symbols used in the study of aircraft stability and control</i> |
| ISO 1151-5:1987 | <i>Flight dynamics – Concepts, quantities, and symbols – Part 5: Quantities used in measurements</i> |
| ISO 1151-6:1982 | <i>Terms and symbols for flight dynamics – Part 6: Aircraft geometry</i> |
| ISO 80000-1:2009 | <i>Quantities and Units – General</i> |

| | | | |
|---|---|--|-----------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 77 of 343 |

4 Vocabulary

4.1 Acronyms and Abbreviated Terms


| | |
|---------|--|
| AIAA | American Institute of Aeronautics and Astronautics |
| AND | aircraft nose down |
| ANR | aircraft nose right |
| ANSI | American National Standards Institute |
| CM | center of mass |
| DAVE-ML | Dynamic Aerospace Vehicle Exchange Markup Language |
| DIS | Distributed Interactive Simulation |
| DTD | Document Type Definition |
| FE | Flat Earth coordinate system |
| GE | Geocentric Earth fixed coordinate system |
| HLA | High Level Architecture |
| IC | initial condition |
| ISO | International Organization for Standardization |
| ISQ | International System of Quantities |
| MathML | Mathematical Markup Language |
| MRC | moment reference center |
| MSL | Mean sea level |
| RWD | right wing down |
| SI | Système Internationale d'Unites |
| URL | Uniform Resource Locator |
| WGS | World geodetic system |
| XML | eXtensible Markup Language |

4.2 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

Center of mass

This standard uses center of mass (CM) as the default location for several coordinate systems. The long-standing aeronautical tradition is to refer to this location as the center of gravity (CG). Center of gravity and center of mass are interchangeable for vehicle modeling on or above a large gravitational body in hydrostatic equilibrium like the Earth. However, the difference between CM and CG can become significant when a vehicle maneuvers near small, irregularly shaped gravitational bodies (e.g. asteroids).

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 78 of 343 |

Thus, center of mass is the more correct term for this important aerodynamic and kinematic reference point.

Coordinate system

A measurement system for locating points in space and attached to a reference frame (Stevens and Lewis, 2003). In this standard they will be orthogonal right-handed triads unless specifically noted.

Ground

Smooth surface of the earth at the nadir, not necessarily MSL.

Mean Sea Level

The zero elevation reference in the simulation, normally the geoid. Although many simulations treat MSL and the smooth surface of the earth as equivalent this is not always true. For example, the WGS84 model equates MSL with the geoid, not the smooth surface.

Presentation coordinate system

The specific coordinate system in which a variable or vector is presented (or expressed). For example, a specific vector may be presented (expressed) in the body axis coordinate system, the geocentric Earth (g_e) coordinate system, or one of the alternatives presented in Section 5. The value of the vector's components (e.g. X, Y, & Z) differs depending on the presentation coordinate system. The presentation frame only determines how the vector is expressed as X, Y, and Z components, as the specific vector of an object is invariant with respect to any arbitrary coordinate frame (i.e. they are contravariant rank one tensors). In other words, the specific vector in two presentation frames differs only by a linear transformation (i.e. a rotation matrix). When one "presents" or "expresses" the vector in a presentation coordinate system, that presentation coordinate system is treated as if it is instantaneously fixed relative to the observer for the given time t (even if the presentation coordinate system is translating and rotating relative to the observer).

The presentation coordinate systems is identified in variable names by the initial coordinate system prefix.

Reference frame

Frames for short. A general definition for a reference frame is: three or more non-collinear points on a rigid body define a reference frame (Stevens and Lewis, 2003). Unlike a coordinate system, a reference frame has no fixed origin, it is in essence a rigid body wherein all points are fixed in position relative to each other. The location of a point or vector in a frame is expressed using a specified coordinate system. Any number of points or vectors may be expressed with any number of coordinate systems (with no relative motion) in the same frame. For example, the Earth is often a reference frame and may have the geocentric Earth (g_e) coordinate system attached to the center, and any number of user defined topodetic coordinate systems (such as runways or launch sites) used to locate and orient fixed objects on the Earth. Note however an object moving on or above the surface of the Earth would be in a different reference frame.

Reference coordinate system


The coordinate system that defines the frame of interest of a rotational measurement such as attitude, angular rate or angular acceleration. Identified in variable names by the " α " component. If not present, the default reference coordinate system is the body coordinate system.

Reference point

The point of interest of a translational measurement such as position, velocity or acceleration. Identified in variable names by an " α " component. If not specified, the default reference point is the ownship's center of mass.

Relative coordinate system

A coordinate system that defines the origin of a measurement such as position, velocity or acceleration (translational or rotational). Identified in variable names by the " w_{rt} " component. If not specified, the default relative coordinate system is the same as the presentation coordinate system for translation and

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 79 of 343 |

the locally-level coordinate system for rotations.

Observer coordinate system

A coordinate system from which motion of a point (a velocity, acceleration or higher derivative) is observed (or measured). In many cases this coordinate system is in the same reference frame as the relative coordinate system, however in the most general case, may exist in a different frame. The magnitude and direction of velocity (and higher derivatives) differ depending on the observer coordinate system due to the fact that the relative coordinate system may be in motion relative to the observer. Identified in variable names by the "ObsFr" component. If not specified, the observer coordinate system defaults to the same coordinate system as the relative coordinate system.

Velocity

The first derivative of position; in the general case, can be applied to either translational or rotational rate-of-change of position. This term normally applies to translational motion; the rotational equivalent is normally called "angular rate."

Inertial velocity

The special case of a velocity for which the relative reference and observer coordinate systems are an inertial frame.

Breakpoint

A value of an independent variable at which the value of its dependent variable is specified, or the x coordinate (or abscissa) of a one dimensional table

Confidence interval

An estimate of the computed or perceived accuracy of the data

Dependent variable

An output that is obtained by evaluation of a tabulated function or a MathML expression

EXAMPLE For $C_L(\alpha, \beta)$, C_L is the dependent variable, also called the output.

Independent variable

The input(s) to a function table or a MathML expression

EXAMPLE For $C_L(\alpha, \beta)$, α and β are independent variables.

One-dimensional table

A table whose values are based upon only one independent variable

EXAMPLE $C_L(\alpha)$ may be represented by a one-dimensional table.

Two-dimensional table

A table whose values are based upon two independent variables

EXAMPLE $C_L(\alpha, \beta)$ may be represented by a two-dimensional table.

Static equation


A mathematical statement where the output (left hand side) does not have direct dependence (right hand side) on a simulation state

Simulation states (and state derivatives)

In the formulation of a non-linear simulation model shown as

$$\begin{aligned}\dot{x} &= f_1\{x(t), u(t), w(t)\} \\ y &= f_2\{x(t), u(t)\}\end{aligned}$$

where

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 80 of 343 |

x represents a vector of the simulation states.

\dot{x} represents a vector of the simulation state derivatives.

u represents a vector of the simulation controls

y represents a vector of the simulation outputs

w represents a vector of disturbances

Function Table

The numeral set of data points used to represent the value of an independent variable as a function of the value(s) of one or more independent variables

EXAMPLE $C_L(\alpha, \beta)$ may be represented by a function table.

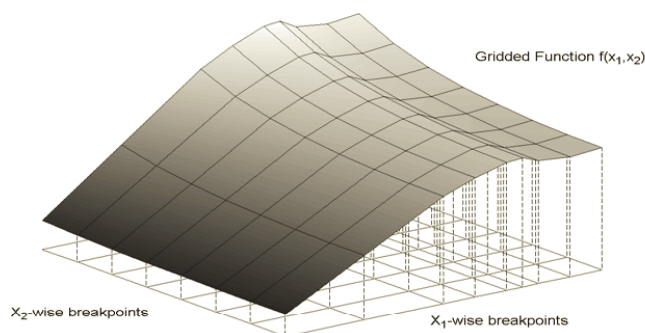
Gridded Table

A multi-dimensional function table in which all independent variable breakpoints are constant across the function range, but not necessarily evenly spaced

NOTE 1 This is sometimes called an orthogonal table.

NOTE 2 All one-dimensional tables are gridded tables.

EXAMPLE A gridded two-dimensional function




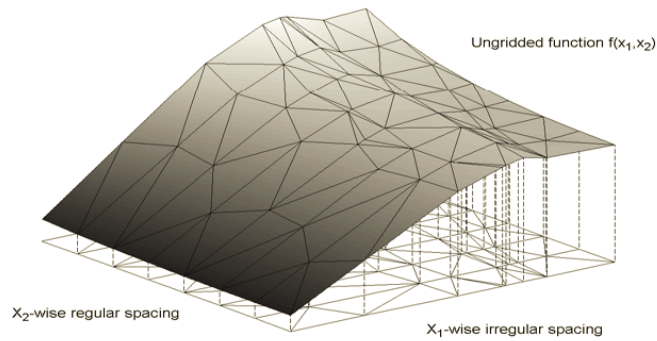
Ungridded Table


A multi-dimensional function table in which the independent variable breakpoints need not be constant across the function range

NOTE This is sometimes called a non-orthogonal table.

EXAMPLE An ungridded two-dimensional function

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 81 of 343 |



| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 82 of 343 |

5 Standard Simulation Coordinate Systems

5.1 Background / Philosophy

Most of the coordinate system definitions discussed herein were taken from existing standards, the *ANSI/AIAA Recommended Practice for Atmospheric and Space Flight Vehicle Coordinate Systems* (ANSI/AIAA R-004-1992) and the *Distributed Interactive Simulation* (DIS Application Protocols, Version 2, IST-CR-90-50, March 1994). AIAA R-004-1992 is based on ISO 1151-1:1988 and ISO 1151-3:1972.

Coordinate system standards are also reflected in the variable naming convention. When applicable, the coordinate system is included in the variable name (see Section 6).

5.1.1 Coordinate System Conventions

In general, ANSI/AIAA R-004-1992 is the normative reference for coordinate system definitions. These coordinate systems are discussed in Table 1. However, it is important to emphasize the correlation of the AIAA document and the *Distributed Interactive Simulation* (DIS) coordinate systems. The geocentric Earth fixed coordinate system and body coordinate system are both used in DIS and High Level Architecture (HLA) simulations.

5.1.1.1 Geocentric Earth Fixed Coordinate System

The Geocentric Earth Fixed Coordinate System (coordinate system 1.1.3 of Table 1) is identical to the DIS "Geocentric Cartesian Coordinate System" (also referred to as "World Coordinate System" in the DIS).

All variables referenced to this coordinate system use "ge" as part of their name for the Geocentric Earth Fixed Coordinate System. This coordinate system is also frequently called "Earth-centered, Earth-fixed."

5.1.1.2 Body Coordinate System

Another standard coordinate system is the Body Coordinate System (coordinate system number 1.1.7 in ANSI/AIAA R-004-1992). This is identical to the DIS "Entity Coordinates System." The body coordinate system is identified in the variable names by "body".


5.1.1.3 Additional Coordinate Systems

In addition to the coordinate systems defined in ANSI/AIAA R-004-1992, this standard has added the Moment Reference Center, Flat Earth, Locally Level, and Vehicle Reference (or Structural) coordinate systems. The Moment Reference Center coordinate system is a special case body coordinate system (number 1.1.7 in ANSI/AIAA R-004-1992, number 1.1.5 in ISO 1151-1:1998). The Flat Earth and Locally Level coordinate systems are respectively variants of the Normal Earth-fixed coordinate system (number 1.1.4 in ANSI/AIAA R-004-1992, number 1.1.2 in ISO 1151-1:1998) and the Vehicle-carried normal Earth coordinate system (number 1.1.6 in ANSI/AIAA R-004-1992, number 1.1.4 in ISO 1151-1:1998). Both these coordinate systems are normally used in conjunction with an assumption that the Earth forms an inertial reference frame. They are useful for simple simulations, and for creating vehicle model validation data. The Vehicle Reference coordinate system is a body coordinate system that may be used to locate vehicle components within the structure of the vehicle.

The moment reference center coordinate (MRC) system may be used to locate objects in the vehicle. Its axes are aligned with the body coordinate system, however, its origin is fixed at the moment reference center of the vehicle while the body coordinate system origin is at the center of mass (CM) and moves as the center of mass (CM) moves.

The moment reference center coordinate system is identified in the variable names by "mrc".

The flat Earth coordinate system is based on a fixed, non-rotating, flat Earth with no mapping to a round Earth coordinate system, and therefore, latitude and longitude are inappropriate (but can be scaled for

| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 83 of 343 |

small maps). The purpose of this coordinate system is to allow, if desired, vehicle checkout simulation to be performed in this coordinate system. This simplifies the use of this standard by simulation facilities that do not normally use a round or oblate spheroidal, rotating Earth model.

The flat Earth coordinate system is identified in the variable names by "fe".

The locally level coordinate system is the reference coordinate system for angles and angular motion. It's origin is fixed at the vehicle center of mass.

The locally level coordinate system is identified in variable names by "ll".

The vehicle reference coordinate system is used to locate vehicle components. It is fixed to the vehicle structure and does not move. The specific definition differs for each vehicle. Sometimes the vehicle system may be the weight and balance reference system for the vehicle. The X origin is often in front of the vehicle, the Y origin in the centerline of the vehicle and the Z origin below the vehicle. The X-axis is often called the fuselage station and is often positive aft, the Y-axis is called butt line and is often positive to right, and the Z-axis is the waterline and is often positive up. However, these definitions may change with the vehicle and a manufacturing reference system may instead be used.

The vehicle reference system is identified in variable names by "vrs".


5.2 Complete List of Coordinate Systems

The coordinate systems that are referenced are taken largely from paragraph 1.1 of ANSI/AIAA R-004-1992. The moment reference center, flat Earth and locally level coordinate systems for atmospheric flight simulation approximation are additional to that reference. A vehicle reference coordinate system is added for the purpose of locating systems and subsystems in the vehicle. Table 1 is the comprehensive list of coordinate systems that may be used under this standard.


The first column in Table 1 provides the abbreviation recommended for each coordinate system. The coordinate system may be referenced in a variable name by use of its abbreviation. See Section 6 on the variable naming convention.

Table 1 — Standard coordinate systems


| Reference Abbreviation | R-004-1992 Paragraph Number | Term | Definition | Symbol |
|--|-----------------------------|--|---|-------------|
| ei (for Earth centered inertial) | 1.1.1 | Geocentric inertial coordinate system (See Appendix D.2 of R-004 for a modification of this system used for launch vehicles.) | An inertial reference system of the FK5 mean equator and equinox of J2000.0 has the origin at the center of the Earth, the X_i -axis being the continuation of the line from the center of the Earth through the center of the Sun toward the vernal equinox, the Z_i -axis pointing in the direction of the mean equatorial plane's north pole, and the Y_i -axis completing the right-hand system. (See Figure 1A in R-004) | $X_iY_iZ_i$ |
| Not used, this forms a basis for other definitions | 1.1.2 | Earth-fixed coordinate system | A right-hand coordinate system, fixed relative to and rotating with the Earth, with the origin and axes directions chosen as appropriate. | $x_0y_0z_0$ |
| ge (also called Earth-centered, | 1.1.3 | Geocentric Earth-fixed coordinate system | A system with both the origin and axes fixed relative to and rotating with the Earth (1.1.2). The origin is at the center of the Earth, the x_g -axis being the continuation of the line | $x_gy_gz_g$ |

| | | | |
|---|--|--|---|
|  | <div>NASA Engineering and Safety Center</div> <div>Technical Assessment Report</div> | <div>Document #:</div> <div>NESC-RP-09-00598</div> | <div>Version:</div> <div>1.0</div> |
| <div>Title:</div> <div>Flight Simulation Model Exchange</div> | | | <div>Page #:</div> <div>84 of 343</div> |


| Reference Abbreviation | R-004-1992 Paragraph Number | Term | Definition | Symbol |
|------------------------|-----------------------------|--|--|-------------|
| Earth-fixed) | | | from the center of the Earth through the intersection of the Greenwich meridian and the equator, the z_G -axis being the mean spin axis of the Earth, positive to the north, and the y_G -axis completing the right-hand system. (See Appendix D.3 in R-004-1992) | |
| | 1.1.4 | Normal Earth-fixed coordinate system | An Earth-fixed coordinate system (1.1.2) in which the z_o -axis is oriented according to the downward vertical passing through the origin (from the origin to the nadir). (See Figure 1C in R-004-1992) | $x_0y_0z_0$ |
| vo | 1.1.5 | Vehicle-carried orbit-defined coordinate system ^a | A system with the origin fixed in the vehicle, <i>(the default being the center of mass)</i> , in which the z_o -axis is directed from the spacecraft toward the nadir, the y_o -axis is normal to the orbit plane (positive to the right when looking in the direction of the spacecraft velocity), and the x_o -axis completes the right-hand system. (See Figure 1A in R-004-1992) | $x_0y_0z_0$ |
| ve | 1.1.6 | Vehicle-carried normal Earth coordinate system ^a | A system in which each axis has the same direction as the corresponding normal Earth-fixed axis, with the origin fixed in the vehicle, <i>the default being the center of mass.</i> | $x_0y_0z_0$ |
| body | 1.1.7 | Body coordinate system ^a | A system fixed in the vehicle, <i>with the default origin being the center of mass</i> , consisting of the following axes: | $x\ y\ z$ |
| | | Longitudinal axis | An axis in the reference plane or, if the origin is outside that plane, in the plane through the origin parallel to the reference plane, and positive forward. ^b In aircraft or missiles, this is normally from the CM forward towards the nose in the vertical plane of symmetry. It is also normally parallel to the waterline of the vehicle. | x |
| | | Lateral axis | An axis normal to the reference plane and positive to the right of the x-axis (henceforth, positive to the right). | y |
| | | Normal axis | An axis that lies in or parallel to the reference plane, whose positive direction is chosen to complete the orthogonal, right-hand system xyz. | z |

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 85 of 343 |

| Reference Abbreviation | R-004-1992 Paragraph Number | Term | Definition | Symbol |
|--|-----------------------------|--|---|--|
| mrc (for moment reference center) | none | <p>A body coordinate system (not in R-004)</p> <p>Longitudinal axis</p> <p>Lateral axis</p> <p>Normal axis</p> | <p>This is a body coordinate system. The default origin is not fixed at the center of mass, but at the moment reference center (mrc) and therefore does not move. It consists of the following axes:</p> <p>An axis in the reference plane or, if the origin is outside that plane, in the plane through the origin parallel to the reference plane, and positive forward.^b In aircraft or missiles, this is normally from the MRC forward towards the nose in the vertical plane of symmetry. It is also normally parallel to the waterline of the vehicle.</p> <p>An axis normal to the reference plane and positive to the right.</p> <p>An axis that lies in or parallel to the reference plane, whose positive direction is chosen to complete the orthogonal, right-hand system xyz.</p> | $x_M y_M z_M$ |
| wind (for wind coordinate system) | 1.1.8 | <p>Air-path system^a</p> <p>x_a-axis; air-path axis</p> <p>y_a-axis; lateral air-path axis; cross-stream axis</p> <p>z_a-axis; normal air-path axis</p> | <p>A vehicle carried system with the origin fixed in the vehicle, <i>located at</i> the center of mass, consisting of the following axes:</p> <p>An axis in the direction of the vehicle velocity relative to the air</p> <p>An axis normal to the air-path axis and positive to the right of the plane formed by the x_a and z_a axes.</p> <p>An axis</p> <ul style="list-style-type: none"> in the reference plane or, if the origin is outside that plane, parallel to the reference plane, and normal to the air-path axis. <p>The positive direction of the z_a-axis is chosen so as to complete the orthogonal, right-hand system $x_a y_a z_a$.</p> | $x_a y_a z_a$ x_a y_a z_a |
| sa (for stability axis system) | 1.1.9 | Intermediate coordinate system ^a | A system with the origin fixed in the vehicle, <i>located at</i> the center of mass, consisting of the following axes. | $x_s y_s z_s$ |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 86 of 343 |

| Reference Abbreviation | R-004-1992 Paragraph Number | Term | Definition | Symbol |
|------------------------|-----------------------------|--|---|------------------------|
| | | x_s -axis | The projection of the air-path x axis on the reference plane, or, if the origin is outside that lane, on the plane through the origin, parallel to the reference plane. | x_s |
| | | y_s -axis | An axis normal to the reference plane and positive to the right, coinciding with or parallel to the lateral axis (1.1.7). | y_s |
| | | z_s -axis | An axis that coincides with or is parallel to the normal air-path axis so as to complete the orthogonal right-hand system. | z_s |
| f _p | 1.1.10 | Flight-path coordinate system ^a | <p>A system with the origin fixed in the vehicle (at the center of mass) and in which the x_k-axis is in the direction of the flight-path velocity relative to the Earth.</p> <p>The y_k axis is normal to the plane of symmetry and positive to the right.</p> <p>The z_k axis completes the orthogonal right-hand system</p> | $x_k y_k z_k$ |
| aa | 1.1.11 | Total-angle-of-attack coordinate system ^a (USA practice: aeroballistic coordinate system.) | A system with the origin fixed in the vehicle, at the center of mass, in which the x_l -axis is coincident with the x -axis in the body coordinate system (1.1.7). The y_l -axis is perpendicular to the plane formed by the x_l -axis and the velocity vector, positive to the right. The z_l -axis is formed to complete the orthogonal, right-hand system. | $x_l y_l z_l$ |
| f _e | None | Flat Earth system (not in R-004) | The Flat Earth coordinate system origin is situated on the Earth's surface directly under the center of mass of the vehicle at the initialization of the simulation. The X_{FE} -axis points northwards and the Y_{FE} -axis points eastward, with the Z_{FE} -axis down. The X_{FE} and Y_{FE} axes are parallel to the plane of the flat Earth. | $X_{FE} Y_{FE} Z_{FE}$ |
| ll | None | Locally Level coordinate system (not in R-004) | A vehicle related coordinate system (1.1.6) with the origin instantaneously at the ownship center of mass. The Z_{LL} -axis passes through the vehicle center of mass and points towards the nadir. The X_{LL} -axis is parallel to the smooth surface of the Earth and oriented toward true north in the geometric Earth model. The Y_{LL} -axis is | $X_{LL} Y_{LL} Z_{LL}$ |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 87 of 343 |

| Reference Abbreviation | R-004-1992 Paragraph Number | Term | Definition | Symbol |
|--|-----------------------------|--|---|--------|
| | | | parallel to the smooth surface of the Earth completing the right hand triad (East). The locally level coordinate system is valid for geometric or flat Earth models. | |
| vrs | None | Vehicle Reference system (not in R-004) | <p>A vehicle fixed coordinate system used to locate items in the vehicle. It is often the weight and balance coordinate reference system for the vehicle, or the manufacturing coordinate reference system. The VRS may not be a right-handed coordinate system.</p> <p>X-axis is the longitudinal reference. It may be the Fuselage Station line, normally 0 being in front of the vehicle with the coordinate increasing aft.</p> <p>Y-axis is the lateral reference. It may be the Butt line perpendicular to the vertical symmetric plane of the vehicle and in the geometric center of the vehicle. Positive to the right facing forward (Starboard)</p> <p>Z-axis is the vertical reference. It may be the Waterline and its origin is normally under the vehicle, positive up.</p> | |
| <p>^aBy default, the origins of the coordinate systems selected from ANSI/AIAA-R-004-1992 1.1.5 through 1.1.11 coincide <i>and are at the center of mass</i>. If that is not the case, it is necessary to distinguish the different origins by appropriate suffixes and additional coordinate system references.</p> <p>^bThe reference plane should be a plane of symmetry, or a clearly specified alternative. <i>This may be specified by the vehicle reference system (vrs).</i></p> <p>^cItalics indicate clarifications to ANSI/AIAA-R-004-1992.</p> | | | | |

5.3 Summary

This coordinate system standard should be followed for all future equations of motion. It is necessary for unambiguous reference to coordinate systems in simulation variable names.


5.4 References

ANSI/AIAA Recommended Practice R-004-1992, *Atmospheric and Space Flight Vehicle Coordinate Systems*, 28 February 1992.


Distributed Interactive Simulation (DIS Application Protocols, Version 2, IST-CR-90-50, March 1994)

ISO 1151-1:1988, *Flight Dynamics – Concepts, quantities and symbols – Part 1: Aircraft motion relative to the air*, 15 April 1988.

ISO 1151-3:1989, *Flight dynamics – Concepts, quantities, and symbols – Part 3: Derivatives of forces*,

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 88 of 343 |

moments and their coefficients, 01 April 1989.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 89 of 343 |

6 Standard Simulation Variables

6.1 Background / Philosophy

6.1.1 Rationale for Having Standard Variable Name and Naming Conventions

The standard variable names and coordinate system definitions are part of this standard to facilitate communication. They provide a "common language" for information exchange. For example, to unambiguously exchange a function representing a lift coefficient, the minimum information required to be transmitted includes the independent variables used to define the function (such as angle-of-attack, angle-of-sideslip, Mach number, Reynolds number and aircraft configuration), their units, their sign conventions, and their reference coordinate systems. Such an exchange will be facilitated by using standard variable names and coordinate systems.

If a model uses standard variable nomenclature the information defining the model data may be exchanged entirely by reference to this standard. Additionally, adherence to the variable naming convention included herein will allow the list of standard variables to grow as needed by the user community. Use of the convention to maintain consistent variable names will ease user workload and maximize the benefits to be obtained from this standard.

Positions, angles, velocities and angular velocities referred to in this standard are defined in accordance with ANSI/AIAA R-004-1992.

6.2 Variable Naming Convention

The purpose of the naming convention is to provide guidance for the creation of variable names consistent with the standard variable names (Annex A). This will allow expansion of Annex A over time, further expanding the set of names available to facilitate model exchanges.

Variable names are constructed from components that jointly serve to fully define the variable in its particular application. A combined mixed case and underscore variable name convention is used. In variable name components that consist of multiple words, the first letter of each word is capitalized (medial capitals). Where the simulation language in use allows it, and where the logic of the simulation requires it, an underscore may be replaced by a period (.) to indicate an object member, or by parentheses or brackets to indicate an array member.

The following general rules for naming all variables shall be followed.


- Variables shall have meaningful names.
- Variable names shall not exceed 63 characters in length. Brief, but complete, names are most effective.
- Names shall be constructed using US-ASCII 7-bit character encodings.

6.3 Variable Name Methodologies

There are three methods specified for defining variables consistent with this standard. Different methods are described for:

- Position variables (linear or angular), arrays or structures
- Motion variables (velocities, accelerations, or higher derivatives, both linear and angular), arrays or structures
- All other variable names

The naming convention for position variables and for variables describing motion are different than other types of variables because of the general requirements to specify coordinate systems that uniquely define

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 90 of 343 |

position and velocity.

In additional, the following guidelines for capitalization when creating variable names are provided:

- d) The first letter in the variable name is lower case. Similarly, the first letter in the prefix and the first component following the prefix are lower case.
- e) The first letters in acronyms and abbreviations are capitalized.
- f) Distinct components in variable names, after the first component, shall begin with a capital letter.
- g) Units are not capitalized unless the unit abbreviation itself is.

6.3.1 The Physical Basis for the Position, Velocity, Acceleration (and Derivatives thereof) Naming Convention

To ground the discussion of variable names it is useful to refer to a standard dynamics text and to review the equation of Coriolis. Figure 2 below shows the derivation of the three-dimensional linear velocity of point p with respect to coordinate system \mathbf{M} as observed from coordinate system \mathbf{O} . Coordinate system \mathbf{M} has translational and rotation motion relative to \mathbf{O} ; in the figure, ω depicts the angular rate of \mathbf{M} with respect to \mathbf{O} .

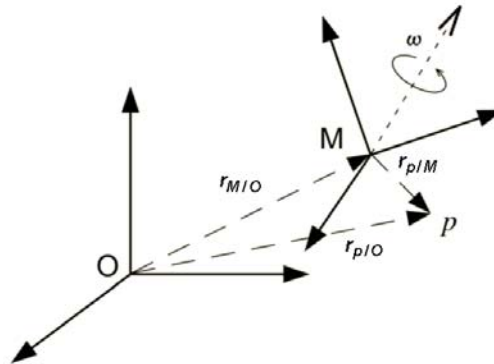


Figure 2 — Rotating reference frames and relative geometry


The velocity of p with respect to \mathbf{M} as observed from \mathbf{O} is the vector difference of the velocity of p with respect to \mathbf{O} and the velocity of \mathbf{M} with respect to \mathbf{O} (both of which are observed from \mathbf{O}):

$${}^O\dot{r}_{p/M} = {}^O\dot{r}_{p/O} - {}^O\dot{r}_{M/O} \quad (1)$$

For this discussion, the vector notation used by Stevens and Lewis is used (see Figure 3 below) but other notations are equally valid. Using the equation of Coriolis (Stevens and Lewis equation 1.2-10), the velocity of p with respect to \mathbf{O} observed from \mathbf{O} is given by:

$${}^O\dot{r}_{p/O} = {}^O\dot{r}_{M/O} + {}^M\dot{r}_{p/M} + \omega_{M/O} \times r_{p/M} \quad (2)$$

The left-hand side term and the first right hand side term in equation (2) are the velocity terms in the right-hand side of equation (1). Combining the two equations produces the following relationship:

| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 91 of 343 |

$${}^O\dot{r}_{p/M} = {}^M\dot{r}_{p/M} + \omega_{M/O} \times r_{p/M} \quad (3)$$

Equation (3) shows that the velocity of p with respect to M as observed from O does not equal the velocity of p with respect to M as observed from M in the general case. This illustrates the need to clearly specify, for derivatives of a linear position vector, the coordinate systems that define the point (this standard designates the point on the vehicle by "Of"), the origin from which the position is measured (this standard designates this by "Wrt"), and the frame in which the observation is made ("ObsFr"). An additional challenge is to achieve this specification using just the ASCII set of characters that are used to compose variable names.

Figure 3 shows how the notation used by Stevens and Lewis are mapped into the coordinate system components of the variable name schema. Within this standard, point p will be illustrative of the Of variable name component, coordinate system M will be illustrative of the Wrt variable name component and coordinate system O will be illustrative of the ObsFr variable name component.

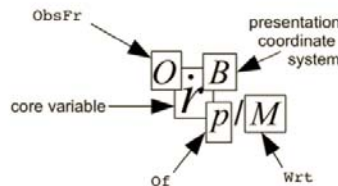


Figure 3 — Mapping Stevens and Lewis notation into variable name components

Another coordinate system that must be specified is that into which the three vector components are resolved in (this standard uses the term 'presentation coordinate system'). This is indicated in the Figure 3 as the right superscript B , which would indicate which coordinate system is used to resolve the vector into three scalar components.

In order to define position, velocity, acceleration or higher derivative variables (both translational and rotational), it is often necessary to specify each of these various coordinate systems. The kinematic requirements to clearly define these variables are presented below.

Positions: For positions (including rotational attitudes), the variable name must specify the origin from which the position is being measured. The name also must specify the coordinate system in which the vector is being resolved.

Take, for example, the core variable name

`position`

This name alone is meaningless. Therefore, it is necessary to describe what the position is representing:


`positionOfPilotEye`

This is still ambiguous as it necessary to specify both the point from which the pilot's eyepoint is being measured and into which coordinate system the position vector is being resolved.

`positionOfPilotEyeWrtCm`

This indicates what point is being located relative to what reference point, and therefore a relative position vector may be defined in 3-space. However, without knowing in which coordinate system the vector is being resolved, any number of coordinate systems could be used. Thus

`bodyPositionOfPilotEyeWrtCm`

| | | | |
|---|--|--|------------------------------------|
|  | <div>NASA Engineering and Safety Center</div> <div>Technical Assessment Report</div> | <div>Document #:</div> <div>NESC-RP-09-00598</div> | <div>Version:</div> <div>1.0</div> |
| <div>Title:</div> <div>Flight Simulation Model Exchange</div> | <div>Page #:</div> <div>92 of 343</div> | | |

This is a complete and unambiguous variable name representing a three-dimensional position. To define the name of any of the three body coordinate system axes, we need to append the name of the appropriate axis and units of measurement:

| |
|---|
| <code>bodyPositionOfPilotEyeWrtCm_ft_X</code> |
| This defines a scalar variable representing the X-body axis offset of the eyepoint from the center of mass, measured in feet. |

Attitudes: Attitude (rotational position) is the orientation of one coordinate system relative to another; therefore, two coordinate systems are required (either explicit or implied) in the variable name to define an attitude. These axis systems are specified using the 'of' and 'wrt' components. The presentation coordinate system is not used because attitude (either as a quaternion, Euler angles, or rotation cosine matrix) is not a vector quantity resolved into X, Y, and Z components.

If the attitude is expressed as a set of Euler angles, the aeronautical convention of yaw-pitch-roll (3-2-1) rotation sequence is the default. To specify a different rotation sequence, the sequence should be appended to the Euler angle core name, e.g. `eulerAngle313` for 3-1-3 rotations. To avoid confusion, for any rotation sequence other than 3-2-1, `_First`, `_Second`, `_Third` should be used for angle selectors in lieu of `_Roll`, `_Pitch`, `_Yaw`.

For example:


| |
|---|
| <code>eulerAngleOfIssWrtEi_rad_Pitch</code> |
| This variable represents the pitch attitude (rotation about the Y axis) of the user-defined International Space Station (<i>Iss</i>) coordinate system relative to the Earth-centered inertial (<i>ei</i>) coordinate system, measured in radians. This rotation uses the default yaw-pitch-roll (3-2-1) rotation convention. |

| |
|---|
| <code>eulerAngle313OfIssWrtOrion_rad_Second</code> |
| This variable represents the second rotation angle of the International Space Station (<i>Iss</i>) coordinate system relative to another user-defined (<i>Orion</i>) spacecraft coordinate system measured in radians. This variable uses yaw-roll-yaw (3-1-3) rotation convention. |

| |
|--|
| <code>eulerAngleOfImuWrtBody_rad[_Roll _Pitch _Yaw]</code> |
| This variable represents the three Euler angles of a user-defined inertial measurement unit (<i>Imu</i>) coordinate system relative to the body coordinate system. |

| |
|---|
| <code>eulerAngleOfImu1WrtImu2_rad[_Roll _Pitch _Yaw]</code> |
| This variable represents the three Euler angles of a user-defined inertial measurement unit (<i>Imu1</i>) coordinate system relative to an <i>Imu2</i> coordinate system, using the default yaw, pitch, roll (3-2-1) rotation convention. |

Derivatives of position (translational or rotational): For variables representing derivatives of *translational* positions (velocities, accelerations and higher derivatives thereof) the observer coordinate system must be specified by the naming methodology. The observer coordinate system exists in the reference frame from which the movement (a velocity, acceleration or higher derivative) is observed (or measured). In many cases this is the same reference frame as the relative coordinate system (defined by the *wrt* component) used to specify the position of the object being observed, but in the most general

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 93 of 343 |

case may be a different frame. The magnitude and direction of velocity (and higher derivatives) varies with selection of the observer's coordinate system since the relative coordinate system may be moving relative to the observer's coordinate system.

For *rotational* derivatives, it is unnecessary to specify an observer's coordinate system, but both coordinate frames that describe the rotational derivatives are necessary (both *of* and *wrt* components).

For example:

| |
|---|
| <code>eiAngularRateOfIssWrtOrion_rad_s_Y</code> |
|---|

| |
|---|
| This variable represents the angular rate of the ISS coordinate system relative to the Orion spacecraft coordinate system. This is the angular velocity vector is resolved to the Earth-centered inertial (ei) coordinate system to measure the Y component in that system. |
|---|

6.3.2 New Position Variables Naming Convention

The methodology for creating and defining a position variable (linear or angular) that is consistent with the requirements of this standard are as follows.

- Each variable name may have up to nine components.
- With the exception of the core name, all components are optional and should only be used if required by the application. Units must be specified unless the variable is non-dimensional and then the *_nd* units specification is encouraged.

The variable name components are listed immediately below. Descriptions of all the components follow in this section.

- <variable domain>*
- _<dynamic equation formulation prefix>_*
- <presentation coordinate system>*
- <core name>* — the only required component
- of<a point for positions or coordinate system for angles, normally on the vehicle>*

If omitted in the variable name, *of* defaults to the Cm for translational position and the body coordinate system for rotational position.


- wrt<"With respect to" a point or coordinate system>*

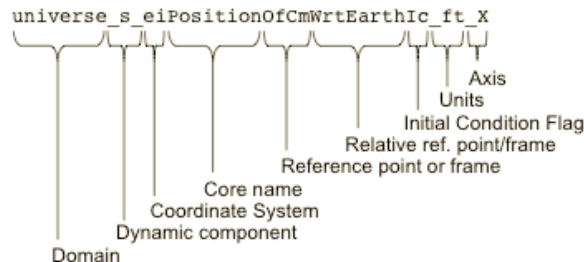
If omitted in the variable name, *wrt* defaults to the presentation coordinate system for linear positions and to the locally level coordinate system (11) for angular position.

- IC* — initial condition designation
- _<units>*
- _<specific axis of the presentation coordinate system>*

Rarely are all 9 components of a name used.

For example:

| | | | |
|---|--|--|-------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | |
| | | | Page #: 94 of 343 |



6.3.3 New Velocity, Acceleration or Higher Derivative Motion Variables Naming Convention

The methodology for creating and defining velocity and acceleration variables (or higher derivatives) consistent with the requirements of this standard are as follows:

- Each variable name may have up to ten components.
- With the exception of the core name, all components are optional and should only be used if required by the application. Units must be specified unless the variable is non-dimensional and then the `_nd` units specification is encouraged.

The variable name components are listed immediately below. Descriptions of all the components follow in this section.

- `<variable domain>`
- `_<dynamic equation formulation prefix>_`
- `<presentation coordinate system>`
- `<core name>` — the only required component
- `Of<a point for translation or coordinate system for rotation, normally on the vehicle>`

If omitted, `Of` defaults to the `Cm` for translation derivatives and the body coordinate system (`body`) for rotational derivatives.

- `Wrt<"With respect to" a point, frame or coordinate system>`

The `Wrt` component (relative coordinate system) may be omitted; if so, the relative coordinate system defaults to the presentation coordinate system for translational variables and the locally-level coordinate (11) system for rotational variables.


- `ObsFr<"Observed From" coordinate system, only used for translational motion>`

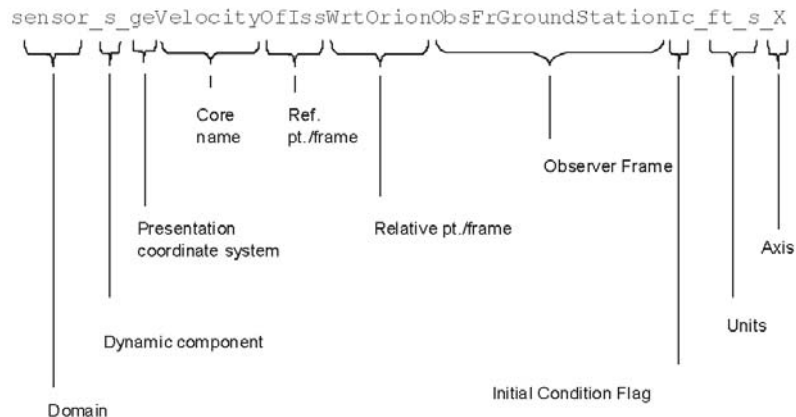
If "ObsFr" is not specified, it defaults to the same coordinate system specified by the relative coordinate system (the `Wrt` component). If the relative coordinate system is not present, `ObsFr` defaults to the presentation coordinate system.

- `Ic` — initial condition designation
- `_<units>`
- `_<specific axis of the presentation coordinate system>`

Rarely are all 10 components of a name used.

For example:

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 95 of 343 |




6.3.4 New General Variables Naming Convention

The methodology for defining variables other than positions and derivatives thereof that is consistent with the requirements of this standard are as follows.

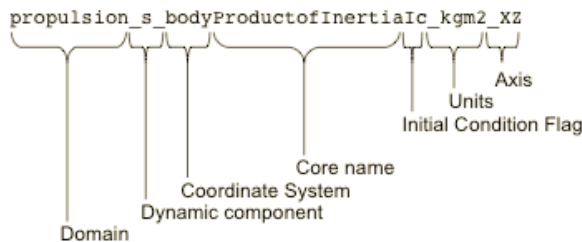
- Each variable name may have up to seven components.
- With the exception of the core name, all components are optional and should only be used if required by the application. Units must be specified unless the variable is non-dimensional and then the `_nd` units specification is encouraged.

The variable name components are listed immediately below. Descriptions of all the components follow in this section.

- `<variable domain>`
- `_<dynamic equation formulation prefix>_`
- `<presentation coordinate system>`
- `<core name>` — the only required component
- `Ic` — initial condition designation
- `_<units>`
- `_<specific axis of the presentation coordinate system>`

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 96 of 343 |

For example:



6.3.5 Adapting the Naming Convention to Hierarchical and Nested Data Representations

The naming methodology provides all the essential information about a variable in its name. This convention is concise for flat data representations (e.g. single-datum variables, arrays, common blocks). However, the convention can lead to repetition of information if applied to the members of hierarchical and nested data structures (e.g. classes, structures, records) since structure organization might parallel one or more of the variable name components. For example, a developer could create a structure to hold all of the variables in an aerodynamics model. The developer could then declare an instance of the structure with the name "aero;" the structure name would repeat information in the variable source domain component of its member variables.

An example of a "flat" variable name is:

`aero_bodyForceCoefficient_X` where "aero" is the variable domain

Prepending the name of the structure to the standard variable name could result in an expression like the one below:

`aero.aero_bodyForceCoefficient_X`

Such repetition can lead to unnecessarily long expressions. To avoid such repetition, developers may use the following guidelines to adapt the naming convention to hierarchical and nested data structures. First, when a level of a structure represents an organization of data that is equivalent to a variable name component, the developer should use the naming rules for that component to name instances of that structure level. Second, if a component of the variable name appears at a higher level or lower level, the developer should not include that component in the variable names at the current level. Using these guidelines, the example above can be changed to:

`aero.bodyForceCoefficient_X`


If the developer made a further change to represent a vector as a structure and replaced the X, Y, and Z variables for the body force coefficient with that structure, the above expression would change to:

`aero.bodyForceCoefficient.X`

To meet the intent of the guidelines, it is not necessary that the structure levels address the variable name components in the same order that the convention specifies for variable names. The intent of the naming convention is to unambiguously identify the information represented by a variable; it is not intended to shape data design. Thus, the name components can appear in a different order for a hierarchical or nested data expression. For example:

`bodyForce_lbf.aero.X`

In this example, the data design is such that all the external forces on a vehicle (expressed in body coordinates and in units of pound-force) are collected in a structure whose instance is named "bodyForce" and whose members represent each generator of force as an instance of a structure representing a vector. The variable source domain appears after the core name and units due to the chosen data design. Even so, this data expression unambiguously identifies the variable as effectively as the equivalent scalar variable name, `aero_bodyForce_lbf_X`.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 97 of 343 |

6.4 Components Used to Create Variable Names

6.4.1 Variable Domain Component

This represents the domain in which the variable is calculated. In object-oriented design, it could logically be the object. The domain is normally not included if it (or the object) is the vehicle or aircraft being simulated, for example, airspeed.

In some cases the domain name component only provides background information when exchanging models. For example, in one simulation architecture the domain for `ambientPressure_N_m2` might be "environment" and another architecture the domain might be "atmosphere". The core component of the name is the key. For example:

`environment_ambientPressure_N_m2` in one simulation architecture is identical to
`atmosphere_ambientPressure_N_m2` in an another simulation architecture


However in some cases the domain component is critical. For example:

`aero_bodyForce_lbf_X` and `thrust_bodyForce_lbf_X` are two different variables, both are body axis forces but one comes from the propulsion system model and one from the aerodynamic model. It is this type of variable where domain must be included.

Some domain examples are presented in Table 2. The domain names presented here are not part of any standard; instead they are presented here as examples.

Table 2 — Examples of domain names

| | |
|----------------------------------|--|
| aero | aerodynamic models |
| airLaunchedWeapon | modeling of munitions launched into the air that have their own dynamics; includes Missile as a sub-domain |
| cautionAndWarning | caution and warning simulation |
| cockpit | input/output from/to cockpit instruments and controls |
| controlLaw | simulation of a control algorithm |
| controlLoading | models of the control system feel |
| controlSurface | simulation of an aerodynamic control effector |
| controlSystem | collective model of control laws and control effectors on a vehicle |
| electrical | models of the electrical system |
| engine (or thrust or propulsion) | thrust generation models |
| environment | atmospheric models (ambient properties, wind, clouds, etc.) |
| failureSystem | failure modeling and fault injection |
| fltDirect | flight director models |
| fuelSystem | fuel system models |
| gun | model of vehicle mounted guns |
| hydraulics | hydraulic system models |


| | | | |
|---|---|---|-------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 98 of 343 |

| | |
|-----------------------|---|
| landingGear | landing gear models |
| massProperties | tree-based modeling of vehicle mass and moments of inertia |
| missile | missile models. Domain could be more specific, for example <code>missileAim9x</code> . |
| motion | motion system models and algorithms |
| navigationDatabase | mapping of waypoints, airports, runways, legs, procedures, and navigation transmitters (all of which are subdomains) |
| navigationReceiver | modeling of signal-based navigation sensors |
| navigationTransmitter | modeling of navigation signal generators (e.g. radios, GPS) |
| parachute | parachute models |
| propulsion | models the collection of thrust generators (engines) on a vehicle |
| radar | models the radar system. Domain could be more specific, for example <code>radarApg79</code>) |
| relGeom | relative state (position, velocity, and acceleration) of each vehicle to each other vehicle |
| sensor | models of sensors |
| sensorSystem | modeling the collection of sensors on a vehicle |
| sim | Domain encompassing control of the simulation, configuration of a simulation run, control of mathematical techniques such as integration type, etc. |
| vehicle | modeling of the vehicle as a cooperating system of other domain models |
| weaponSystem | collective model of guns and air-launched weapons on a vehicle |
| wheel | landing gear wheel models |
| world | world model (shape, dynamics, and reference time(s) plus navigation database and environment domains) |
| universe | domain encompassing world, vehicle, and relative geometry domains |

NOTE Users may add as many domains as needed to clearly identify the variable.

Variable name examples using "aero" and "thrust" include:

- a) `aero_bodyForce_lbf_X`
- b) `thrust_bodyForce_lbf_X`
- c) `aero_bodyForceCoefficient_X`

| | | | |
|---|--|--|---|
|  | <div>NASA Engineering and Safety Center</div> <div>Technical Assessment Report</div> | <div>Document #:</div> <div>NESC-RP-09-00598</div> | <div>Version:</div> <div>1.0</div> |
| <div>Title:</div> <div>Flight Simulation Model Exchange</div> | | | <div>Page #:</div> <div>99 of 343</div> |

d) `thrust.bodyForceCoefficient_X` — this is an example of `thrust` as a structure.

e) `thrust.bodyForceCoefficient(X)`

6.4.2 Dynamic Equation Formulation Prefix Component

The dynamic equation formulation prefix is used to identify the most important dynamic variables in the simulation, the states (\dot{x}) and their derivatives (\ddot{x}), inputs (u), outputs (y), and disturbances (w) as presented in the equation below. These variables characterize the resultant dynamic response of a vehicle as shown in the equations below. In addition to these variables, the standard allows the prefix to separately designate simulation control variables (c). Simulation control variables are used to modify the behavior of the model during simulation and are not part of the vehicle model, while inputs (u) are variables that represent the inputs to the vehicle model which may include pilot control positions. Finally, in simulation or analysis where noise and environmental disturbances are modeled, the disturbances (w) are the final component in the simulation of the total system dynamics.

$$\begin{aligned}\dot{x} &= f_1\{x(t), u(t), w(t)\} \\ y &= f_2\{x(t), u(t)\}\end{aligned}$$

The prefix shall be separated from the body of the variable by an underscore (`_`) and from the domain name by an underscore (or a period if preceded by a member of a structure or class). The leading underscore is not permitted if a domain name is not present.

6.4.2.1 Identification of Simulation Model States and State Derivatives

The states (x) and state derivatives (\dot{x}) are those variables that make the simulation dynamic and are the key variables in a flight simulation model. Basically, any variable that is mathematically integrated is a state derivative. The result of integration of a state derivative over a period of time is a change in the value of the corresponding state over that time. This is true for any integration in a simulation. If the user controls the changes in all the states, they control the trajectory of the simulated model. The time histories of the states and inputs are the key variables required for validation. All outputs are computed directly or indirectly from states and inputs.

The formulation of the equations of motion and the model itself determines what variables are states. This naming convention is not meant to standardize on any variable as a state, but allows the simulation engineer to explicitly identify states in the model implementation, making it easier to document and exchange the models.


Examples:

| | |
|---|--|
| <code>x_bodyVelocityWrtEi_ft_s_X</code> | <code>x_</code> prefix indicates that this variable is a state |
| <code>dx_bodyAccelerationWrtEi_ft_s2_X</code> | <code>dx_</code> prefix indicates that this variable is a state derivative |

6.4.2.2 Identification of Simulation Model Inputs

The simulation model inputs (u) are those variables that provide the pilot or autopilot inputs to the vehicle model. These are also called controls in many references. As with the states and state derivatives, the model inputs are key variables for validation. All model outputs are computed directly or indirectly from model states and inputs.

The formulation of the model itself determines which variables are inputs. This naming convention is not meant to standardize on any variable as an input, but allows the simulation engineer to explicitly identify

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 100 of 343 |

them, making it easier to document models, exchange them, and verify them.

Examples:

| | |
|--|---|
| <code>u_controlSurfacePos_deg_avgAileron</code> | <code>u_</code> prefix indicates that this is a model input |
| <code>controlLaw_u_controlSurfacePos_deg_avgAileron</code> | same variable name with domain prefix |
| <code>controlLaw.u_controlSurfacePos_deg_avgAileron</code> | same variable name in a hierarchical architecture |
| <code>u_pilotControlPos_rad_long</code> | Another example of the longitudinal pilot input |

6.4.2.3 Identification of Simulation Model Disturbances

The disturbances (w) are those variables that provide environmental disturbances or system noise to the simulation models.

Disturbances may be inserted into the vehicle model, environment, or equations of motion, depending upon implementation schemes. This naming convention is not meant to standardize on any variable as a disturbance, but allows the simulation engineer to explicitly identify disturbances, making it easier to document models, exchange them, and verify them.

Examples:


| | |
|---|--|
| <code>w_bodyAngularRateTurbulenceWrtGe_deg_s_Yaw</code> | <code>w_</code> prefix indicates that this variable is a disturbance |
| <code>environment_w_bodyAngularRateTurbulenceWrtGe_deg_s_Yaw</code> | same variable name with domain (environment) added |
| <code>environment.w_bodyAngularRateTurbulenceWrtGe_deg_s_Yaw</code> | same variable name in a hierarchal architecture |

6.4.2.4 Identification of Simulation Model Outputs

The simulation model outputs (y) are those variables that are the outputs of the physics of the simulation models as formulated by the state equations. This is meant to assist in the specification of the state equations, mainly to help simplify model exchanges between simulations used for analysis and those used for real-time man in the loop or hardware in the loop simulations.

Example:

| | |
|--|--|
| <code>y_leftHorizontalActuatorRamPosition_deg</code> | <code>y_</code> prefix indicates that this variable is a model output. |
|--|--|

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 101 of 343 |

6.4.2.5 Identification of Simulation Controls

The simulation controls (*c*) are those variables that provide the simulation operator control of the simulation [not to be confused with simulation model inputs (*u*)]. The simulation controls should not affect any vehicle states, state derivatives or outputs.

The software and hardware architecture of the simulation determines what variables are simulation controls. This naming convention is not meant to standardize on any variable as an control, but allows the simulation engineer to explicitly identify simulation controls. Clear definition of simulation controls makes validation of a simulation much easier after a model is exchanged.

Examples:

| | |
|--------------------------------|---|
| <code>c_simDuration_s</code> | <code>c_</code> prefix indicates that this variable is a simulation control |
| <code>c_deltaTime_s</code> | another example |
| <code>sim_c_deltaTime_s</code> | same variable name with domain added |
| <code>sim.c_deltaTime_s</code> | same variable name in a hierarchal architecture |

6.4.3 Presentation Coordinate System Component

This is the coordinate or reference system to which the variable is referenced or in which it is measured (it is indicated by the "B" in Figure 3). Table 1 specifies the standard coordinate system abbreviations that should be used. If no coordinate system pertains to the variable or the core variable name needs no reference system to be unambiguous (e.g. Airspeed), this part of the variable name may be omitted.


6.4.3.1 Conventions Used

Earth fixed and local coordinate systems by convention use X, Y, Z, for both translation and (X, Y, Z), (Pitch, Roll, and Yaw), or (First, Second, Third) for rotation axis indices. The origin and attitude of local coordinate systems (flat Earth for example) may be user defined (such as N, E, D). Local coordinate systems are meant for runway, test range, target reference, navigational aids, etc.

6.4.3.2 Variable Name Examples

The following variable names are provided as examples.

| | |
|--|--|
| <code>x_bodyAngularRate_rad_s_Roll</code> <code>x_bodyAngularRate_rad_s.Roll</code> <code>x_bodyAngularRate_rad_s_X</code> | <p>These are all equivalent variable names where <code>body</code> is the coordinate system and <code>roll</code> is the specific axis in the body axis system, roll indicating angular motion about the longitudinal axis relative to the locally-level frame (<code>wrt</code> defaults to locally-level for rotational variables).</p> <p>NOTE In this example the variable is designated as a state.</p> |
| <code>x_bodyVelocityWrtEi_m_s_X</code> <code>x_bodyVelocityWrtEi_m_s.X</code> | <p>These represent translational inertial velocity in the body coordinate system along the longitudinal axis (the translational variable analogous to the rotational variable above).</p> <p>These are all equivalent variable names.</p> |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 102 of 343 |

| | |
|---|---|
| <code>geVelocity_m_s_Y</code> | This represents a translational velocity with <code>ge</code> specified as the coordinate system and <code>Y</code> as the specific axis. This non-inertial velocity of the CM is relative to and measured in the geocentric earth-fixed (<code>ge</code>) coordinate system. |
| <code>bodyTurbulenceVelocityWrtGe_ft_s_Z</code> <code>bodyTurbulenceVelocityWrtGe_ft_s [3]</code> <code>bodyTurbulenceVelocityWrtGe_ft_s.Z</code> | These are all equivalent variable names where <code>body</code> is the coordinate system and <code>Z</code> is the specific axis in the body coordinate system, <code>z</code> indicating vertical translational motion. Also illustrated as a vector and structure. |
| <code>runway22VelocityOfLeftWheelWrtTd_ft_s_Z</code> | Here <code>runway22</code> is the coordinate system (user defined) and <code>Z</code> is the specific axis, also indicating translational motion. <code>LeftWheel</code> is the point on the vehicle and <code>Td</code> (touchdown point) is the reference point. |
| <code>bodyAccelOfPilotEyeWrtEi_m_s2_Y</code> | Here <code>body</code> is the coordinate system and <code>Y</code> is the specific axis, also indicating translational motion. Design pilot eyepoint is the point on the vehicle. |
| <code>x_eiVelocity_ft_s_X</code> | This is a case where the equations of motion are formulated such that the variable is a state, resolved in the earth centered inertial (<code>ei</code>) coordinate system |
| <code>eiVelocity_ft_s_X</code> | This is a case where the equations of motion are formulated such that the variable is not a state |
| <code>x_llVelocity_ft_s_X</code> | Locally Level coordinate system |
| <code>x_feVelocity_ft_s_X</code> | Flat Earth coordinate system |
| <code>bodyAngularRate_rad_s_Pitch</code> | |
| <code>bodyAngularRate_rad_s_Roll</code> | |
| <code>bodyAngularAccel_rad_s2_Yaw</code> | |


Note that the standard allows (X, Y, Z) or (Roll, Pitch, Yaw) or (First, Second, Third) as selectors for rotational positions and derivatives, since that is widely conventional. However, since the overall objective of the standard is to form a framework for clear communication between simulation facilities, the use of X, Y, Z selectors is acceptable. The appropriate core variable name shall be used to indicate whether the variable is a translational or rotational variable.

6.4.4 Core Variable Name Component

This is the most specific (hence core) name for the variable. All variable names shall include this component of the name.

Core variable name examples are as follows.


- `velocity` convention for velocities
- `angularRate` convention for angular rates

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 103 of 343 |

- accel convention for translational accelerations
- angularAccel convention for angular accelerations
- pilotControlPos conventions for pilot controls
- pilotControlRate
- pilotControlAccel
- pilotControlForce
- copilotControlPos conventions for pilot controls
- copilotControlRate
- copilotControlAccel
- copilotControlForce
- controlSurfacePos conventions for control surfaces
- controlSurfaceRate
- controlSurfaceAccel
- controlSurfaceHingeMoment
- liftCoefficient
- dragCoefficient
- forceCoefficient
- turbulenceVelocity
- angleOfAttack
- angleOfSideslip
- cosineOfAngleOfSideslip
- thrust
- torque

The following extended variable names are provided as examples.

- x_bodyAngularRate_rad_s_Roll
- bodyTurbulenceVelocityWrtGe_ft_s_X
- geVelocity_ft_s_Z
- geVelocity_m_s_Z
- pilotControlPos_deg_long
- pilotControlPos_deg_lat
- pilotControlRate_deg_s_pedal
- pilotControlAccel_deg_s2_long

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 104 of 343 |

- copilotControlPos_deg_long
- copilotControlPos_deg_lat
- copilotControlRate_deg_s_long
- copilotControlAccel_deg_s2_long
- controlSurfacePos_deg_elevator[number of surfaces]
- controlSurfaceRate_deg_s_rudder[number of surfaces]
- controlSurfaceAccel_deg_s2_aileron[number of surfaces]
- controlSurfaceHingeMoment_ftlbf_canard[number of surfaces]
- angleOfAttack_rad
- angleOfSideslip_deg
- cosineOfAngleOfSideslip
- controlSurfacePos_deg_aileron
- totalPressure_N_m2
- ambientPressure_N_m2
- totalLiftCoefficient
- aeroBodyForceCoefficient
- aeroBodyForce_lbf
- aeroBodyForce_N
- thrustBodyForce_N

6.4.5 Reference Point or Coordinate System (“of”)


This component of the name is designed to clarify positions, velocities and accelerations and is normally omitted if the variable is not a position, velocity or acceleration. However, it may be used for any variable if desired. This component describes which point or object that is being specified. “of” is used to specify the point or object (this is point *p* in Figure 2).

For those who prefer shorter variable names, the standard adopts the convention that if the point or location on the vehicle is the center of mass for translational motion variables, then the reference point may be omitted. For rotational motion, the default reference coordinate system is the body axis coordinate system.

Reference points may be defined by the user and depend on the object the variable is describing.

Examples of reference points are as follows.

- OfCm the center of mass is the default point, so “OfCm” is normally omitted in any variable name.
- OfImu or OfImu1, OfImu2, OfImuLtn200, etc.
- OfSensor or OfRadar, OfFlir, OfRadarApg67, etc.
- OfMrc for moment reference center

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 105 of 343 |


- `OfPilotEye` for the pilot eye point
- `OfRadAlt` for radar altimeter
- `OfTerrain` a normal Earth-fixed coordinate system with origin where the vehicle nadir intersects the terrain

The following variable names are provided as examples.

| | |
|--|---|
| <code>bodyPositionOfImuWrtCm_m[3]</code> | This three-element vector locates the Imu relative to the CM in the body axis coordinate system. Note that [3] indicates (for this example) that the referenced variable is a three-element vector. |
| <code>bodyPositionWrtImu_m[3]</code> <code>bodyPositionOfCmWrtImu_m[3]</code> | Both of these vector names refer to the same quantity; it is the opposite of the vector above (they locate the CM relative to the Imu). In the first name "OfCm" is omitted since it is default. |
| <code>eulerAngleOfImuWrtBody_rad[3]</code> | This is the angular equivalent of the first variable above. The 3-2-1 rotation convention is implied. |
| <code>x_bodyAngularRateWrtEi_rad_s[3]</code> | Here element 1 would be about the X-axis (roll), element 2 would be about the Y-axis (pitch) and element 3 would be about the Z-axis (yaw). These are inertial rates since they are measured with respect to the Earth inertial (Ei) coordinate system. |
| <code>bodyVelocityWrtAir_ft_s_X</code> | OfCm is implied |
| <code>bodyVelocityOfCmWrtAir_ft_s_X</code> | Same meaning as above |
| <code>bodyVelocityWrtEi_ft_s_X</code> | Inertial velocity of the CM along the X-body axis |
| <code>bodyVelocityWrtEi_m_s_X</code> | Inertial velocity of the CM along the X-body axis in SI units |
| <code>heightOfCmWrtTerrain_ft</code> | OfCm may be omitted since it is the default |
| <code>heightOfRadAltWrtTerrain_ft</code> | |
| <code>heightOfTerrainWrtWgs84_ft</code> | Height of nadir intersection with terrain above the reference ellipsoid |
| <code>bodyPositionOfPilotEyeWrtCm_ft_X</code> | |
| <code>geLongitudeRateOfImu_deg_s</code> | |
| <code>longitudeOfImuWrtGe_deg</code> <code>geLongitudeOfImu_deg</code> | These are the same scalar quantity. |
| <code>bodyAccelOfPilotWrtEi_ft_2[3]</code> | Inertial acceleration vector in the body axis |

6.4.6 Component Indicating Relative Reference Point or Relative Reference Coordinate System

The relative reference component is generally used in conjunction with the "reference point or location on the vehicle" component described in section 6.4.5. It is primarily used in variables describing position,

| | | | |
|---|--|--|------------------------------------|
|  | <div>NASA Engineering and Safety Center</div> <div>Technical Assessment Report</div> | <div>Document #:</div> <div>NESC-RP-09-00598</div> | <div>Version:</div> <div>1.0</div> |
| <div>Title:</div> <div>Flight Simulation Model Exchange</div> | <div>Page #:</div> <div>106 of 343</div> | | |

velocities and accelerations. This component defines the reference that the motion or position is relative to. This component, preceded by "wrt" (with respect to) in the variable name, is the equivalent of coordinate system **M** in Figure 2, as noted in Figure 3.

For position variables, wrt refers to the reference point for linear positions. For angular positions, wrt refers to the relative coordinate system. For derivatives of position (velocities, accelerations, etc.) wrt is used to define relative motion of two objects.

If "wrt" is omitted then the default points or relative coordinate systems are:

the presentation coordinate system for linear positions and translational motion. For example,

bodyPositionOfImu_m[3]. Here WrtBody is implied.

the locally level coordinate system specified for rotational variables. For example:

eulerAngleOfImu_rad[3]. Here "wrtL1" is implied.

Note: Since for translational motion the "Wrt" defaults to the presentation coordinate system the variable:

bodyVelocity_f_s_X

while a valid variable, has little usefulness because, fully enumerated is:

bodyVelocityOfCmWrtBodyObsFrBody_f_s_X


Body velocity of the Cm with respect to the body is virtually always near zero. It would only represent the movement of the Cm within the body, due to cargo shift, fuel burn, etc. It would not represent velocity of the Cm with respect to a coordinate system outside the aircraft.

Examples of reference points are as follows:

- WrtCm this is commonly used to clarify definitions of positions within the vehicle
- WrtEi identifies a variable that is referenced to inertial space
- WrtMrc moment reference center
- WrtTgt aim point
- WrtImpact the desired weapon impact point
- WrtAir the local atmosphere, used to define air-relative (or wind-relative) motion
- WrtMeanSL mean sea level
- WrtGe the geocentric Earth fixed coordinate system
- WrtGround a normal Earth-fixed coordinate system with origin where the vehicle nadir intersects the smooth surface of the Earth
- WrtTerrain a normal Earth-fixed coordinate system with origin where the vehicle nadir intersects the terrain

The following linear and angular position variable names are provided as examples:

| | |
|--|---|
| <code>bodyPositionOfImuWrtCm_m[3]</code> | <p>This vector locates the Imu relative to the CM in the body axis coordinate system.</p> <p>WrtCm may be omitted since CM is the default reference point for linear position measurements.</p> |
|--|---|

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 107 of 343 |

| | |
|---|--|
| eulerAngleOfImu_rad[3] eulerAngleOfImuWrtLl_rad[3] | This is the angular equivalent of the first variable above. In the first variable "WrtLl" is omitted since the locally-level coordinate system is the default relative coordinate system for angular positions. |
| eulerAngleOfImuWrtBody_rad[3] | This is a vector representing the alignment of the IMU with respect to the aircraft body. |
| eulerAngleOfImu1WrtImu2_rad[3] | This is a vector representing the attitude of Imu1 relative to Imu1. |
| bodyPositionOfPilotEye_ft [3] | WrtBody is implied since the Wrt defaults to the presentation coordinate system. Since the Body coordinate system origin is at the Cm, this variable represents the position of the Pilot design eye with respect to the Cm (+ = eye fwd: right: below Cm) |
| geLongitudeOfImu_deg | WrtGe is implied (since ge is the presentation coordinate system) |
| geLongitude_deg | ofCm is implied when not given. |
| bodyPositionOfCmWrtMrc_ft[3] | |
| heightOfRunwayWrtMeanSL_ft | |

6.4.7 Component Indicating Observer's Coordinate System (Vehicle translational motion variables only)


For variables representing derivatives of linear positions (velocities, accelerations and higher derivatives thereof), the observer's coordinate system (indicated by **ObsFr** for "Observed From")) must be specified. The observer's coordinate system is in that reference frame from which the movement (a velocity, acceleration or higher derivative) is observed or measured. In many cases this is the same reference frame as the relative coordinate system (given by **Wrt**) but in the most general case it may be a different frame. The magnitude and direction of velocity (and higher translational motion derivatives) differ depending on the motion of the observer's coordinate system. This is the coordinate system shown as the upper left superscript in the Stevens and Lewis convention shown in Figure 3 and is illustrated by coordinate system **O** in Figure 2.

It is conventional to omit the observer's coordinate system when it is the same as the reference (**Wrt**) coordinate system. As noted in Section 6.4.6, when the **Wrt** coordinate system is omitted it defaults to the presentation coordinate system for translational variables, so when both the **Wrt** (reference) and the observer's (**ObsFr**) coordinate systems are omitted, the default observer's coordinate system is the presentation coordinate system.


It is neither necessary nor appropriate to specify the observer's coordinate system for rotational motion variables as rotations are invariant with the location of the observer.

Some examples are:

| |
|---|
| geVelocity_ft_s_X |
| Velocity of the ownship center-of-mass in the geocentric Earth coordinate system (velocity along the GE X-axis). Note that the reference point (Of), relative coordinate system (Wrt) and observer's coordinate system (ObsFr) default to the velocity of the center of mass with respect to and |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 108 of 343 |

| | |
|---|--|
| observed from the geocentric Earth-fixed coordinate system since they are omitted. | |
| <code>geVelocityOfCmWrtGeObsFrGe_ft_s_X</code> | |
| This is the same variable as the previous one with the reference point (<code>OfCm</code>), relative coordinate system (<code>WrtGe</code>) and observer coordinate system (<code>ObsFrGe</code>) all explicitly specified (they are not required since they are the defaults). | |
| <code>bodyAccelWrtEi_ft_s2_X</code> | |
| Acceleration of the vehicle center of mass relative to and observed from the Earth-fixed inertial (EI) coordinate system and presented in the body axis coordinate system (acceleration along the body X-axis). Naming convention components that can be implied are omitted. | |
| <code>bodyAccelOfCmWrtEiObsFrEi_ft_s2_X</code> | |
| This is the same variable as the previous one with the reference point, relative coordinate system and observer coordinate system all explicitly specified. | |
| <code>bodyVelocityWrtAir_ft_s_X</code> | |
| This is the air-relative velocity of the CM expressed in body coordinates; the <code>ObsFr</code> component is omitted to indicate that the observer's coordinate system is in the same frame as the steady state air mass reference frame (Air). | |
| <code>bodyVelocityOfCmWrtAirObsFrAir_ft_s_X</code> | |
| Same as the variable above, fully expressed | |
| <code>bodyPositionOfPilotEyeWrtCm_ft_X</code> | |
| The position of the pilot's eyepoint relative to the vehicle center-of-mass along the body X-axis. Note that the sign convention is clear: since the X-axis origin is at the center of mass, and is positive forward, the pilot's eyepoint position is positive when forward of the center of mass. | |
| <code>bodyPositionOfPilotEyeWrtMrc_ft_X</code> | |
| The position of the pilot's eyepoint relative to the moment reference center along the body X-axis. Note that the sign convention is clear: since the body X-axis origin is at the center of mass, and is positive forward, the pilot's eyepoint position is positive when forward of the MRC. | |
| <code>bodyAccelOfPilotWrtEi_ft_s2_[3]</code> | |
| This represents the inertial acceleration of the pilot, resolved into the vehicle's body axes. The <code>ObsFr</code> component is omitted, implying the motion is observed from the <code>wrt</code> coordinate system (here, Earth Inertial). | |
| <code>bodyAccelOfPilotWrtEiObsFrEi_ft_s2_[3]</code> | Same as above. <code>ObsFr</code> explicitly stated. |
| <code>bodyVelocityWrtEi_ft_s_X</code> | Inertial velocity of the CM along the X-body axis. |
| <code>bodyVelocityOfCmWrtEiObsFrEi_ft_s_X</code> | Same meaning as the previous variable, fully expressed |
| <code>runway22VelocityOfLeftWheelWrtTdObsFrTd_ft_s_Z</code> | |
| This is the velocity of the wheel relative to the TD point observed from the TD coordinate system. The user must explicitly define the TD coordinate system, but logically it is in an Earth-fixed reference frame, probably with the origin at the desired touchdown point and aligned with the | |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 109 of 343 |

| |
|---|
| runway. |
| runway22VelocityOfLeftWheelWrtTd_ft_s_Z |
| This is the same variable as above, since omitting ObsFr implies it is the Wrt coordinate system. |
| velocityWrtGround_ft_s |
| This scalar variable is commonly known as groundspeed. |

6.4.8 Component Indicating Initial Variables

A convention proposed by this standard is adding "Ic" to the end of any variable name, before any units, to designate that the variable is an initial condition specification. This can be added to virtually any variable without an underscore separator, conceptually creating a constant, for example:

1. `x_bodyVelocityWrtEiIc_rad_s_X`
2. `grossWeightIc_N`

6.4.9 Units Suffix

The suffix is used to describe the units of the variable. The convention for the suffix is simple and is followed for all variables. When exchanging simulation models, the units of all variables must be specified and this is the mechanism to do so. This will also allow the user, the programmer, and the reader of the code to check for homogeneity of the units and is self-documenting in this respect. Therefore, units shall be included in all variables except variables that are non-dimensional. If required for clarity, "nd" may be used in the units suffix to indicate a non-dimensional variable. Including units has the added advantage of making this standard consistent and acceptable in countries utilizing the international system of units. For example, airspeed is equally acceptable as a standard both for the U.S. system of units and the International system of units.

The standard uses an underscore (`_`) to separate the numerator from the denominator an analogy to exponential notation for the specification of units. For example, the unit expression for cubic feet per second squared (for example) would be `ft3s-2`. Eliminating the superscripts leaves `ft3s-2`. Separating the numerator from the denominator results in `ft3_s2`, since the negative sign in the denominator exponential term is dropped.

With few exceptions, only base units are supported; it is not allowed to have, for example, milliseconds (ms). Here the proper use would be to express that variable in seconds.

Further examples are as follows:

1. `trueAirspeed_ft_s` for feet per second (ft/s)
2. `trueAirspeed_m_s` for meters per second (m/s)
3. `trueAirspeed_kt` for knots (nautical miles per hour)
4. `bodyAccelWrtEi_ft_s2_X` for feet per second squared (ft/s²)

The suffix shall be separated from the body of the variable name by an underscore. The standard unit notations are given in Table 3; SI units and standard abbreviations are included where available.



NASA Engineering and Safety Center Technical Assessment Report

Document #:
**NESC-RP-
09-00598**

Version:
1.0

Title:

Flight Simulation Model Exchange

Page #:
110 of
343

Table 3 — Abbreviation for units-of-measure in standard variable names

| Time | |
|-------------------|------------------|
| second | s ^a |
| minute | min ^e |
| hour | h ^e |
| Length | |
| inch | inch |
| foot | ft |
| meter | m ^a |
| nautical mile | nmi |
| statute mile | smi |
| kilometer | km |
| centimeter | cm |
| millimeter | mm |
| astronomical unit | ua ^e |


| Force | |
|----------------|------------------|
| pound force | lbf |
| Newton | N ^b |
| kilogram force | kgf |
| Mass | |
| kilogram | kg ^a |
| pound mass | lbm |
| slug | slug |
| Solid Angle | |
| steradian | sr ^b |
| Plane Angle | |
| degree | deg |
| radian | rad ^b |
| revolution | rev |

| Temperature | |
|--------------------|------------------|
| degrees Rankine | dgR |
| degrees Celsius | dgC ^d |
| degrees Fahrenheit | dgF |
| Kelvin | dgK ^c |

| Power, energy, work, heat | |
|-------------------------------|------------------|
| energy (British thermal unit) | btu |
| energy (erg) | erg |
| energy (calorie) | Cal |
| energy (joule) | J ^b |
| power (horsepower) | Hp |
| power (watt) | w ^b |
| Electrical units | |
| potential (volt) | v ^b |
| volt, direct current | Vdc ^d |

| | |
|---------------------------|------------------|
| volt, alternating current | Vac ^d |
| current (ampere) | A ^a |
| frequency (hertz) | Hz ^b |
| inductance (henry) | H ^b |
| capacitance (farad) | F ^b |
| charge (coulomb) | C ^b |
| conductance (siemens) | S ^b |
| resistance (ohm) | ohm ^d |

| Other | |
|--|------------------|
| pressure, stress (pascal) | Pa ^b |
| standard gravitational acceleration unit | g |
| luminous intensity (candela) | cd ^a |
| luminous flux (lumen) | lm ^b |
| illuminance (lux) | lx ^b |
| amount of substance (mole) | mol ^a |
| magnetic flux density (tesla) | T ^b |
| magnetic flux (weber) | Wb ^b |
| radioactive activity (becquerel) | Bq ^b |
| absorbed dose (gray) | Gy ^b |
| dose equivalent (sievert) | Sv ^b |
| nautical mile per hour | kt |
| non-dimensional | nd |

| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | |
| | | Page #: 111 of 343 | |

Notes:

- a. SI base unit (reference ISO 80000-1:2009, §6.5.2)
- b. SI derived unit (reference ISO 80000-1:2009, §6.5.3)
- c. SI base unit with modified abbreviation
- d. SI derived unit with modified abbreviation
- e. ISO recognized non-SI unit (reference ISO 80000-1:2009, §6.5.6)

6.4.10 Units-agnostic models

Some models have identical formulations whether the system of measurement is the SI system or the U.S. customary system. The units of the model's outputs depend only on the units of the values that are provided as inputs. These "units-agnostic" models can be reused in simulations with few or no conversions performed on inputs or outputs by the host simulation. To allow the exchange of units-agnostic models, the standard provides a set of abbreviations for generic units that represent the base units that differ between SI and U.S. customary system, namely length, mass, and temperature:

| Unit | Abbreviation |
|-------------|------------------|
| length | L ^a |
| mass | M ^a |
| temperature | dgT ^b |

Notes:

- a. ISQ base unit. (reference ISO 80000-1:2009, §3.7)
- b. ISQ base unit with modified abbreviation

The two systems of measurement use the same unit for time (second). The U.S. customary system does not define units for the base quantities of electric current, luminous intensity, and amount of substance; the SI units (see ISO 80000-1:2009) fill this omission. Therefore, generic units are not required for time, electric current, luminous intensity or amount of substance; the SI unit for these quantities is used for variable names in unit agnostic models.


Examples of variable names using generic units:

- bodyForce_ML_s2_Z
- bodyVelocityWrtGe_L_s_X
- thermalConductivity_ML_s3dgT

Note that the last variable, thermal conductivity, would normally be published in SI units of W/(m²·K) [equal to kg·m/(s³·K)] with a conversion factor to the typical English units of BTU/(hr·ft²·°F), neither of which equals the English unit substitution in the variable name of slug·ft/(s³·°R). So, a host simulation based on U.S. customary units would need to convert the published value to slug·ft/(s³·°R) before passing the value to the model. (A unit conversion is not required in a host simulation based on SI units.) If this model were originally developed for that host simulation, the model developer would likely have placed the necessary conversions from BTU and hours (or from the published SI value) within the model; however, by formulating the model as unit agnostic, responsibility for conversion has been moved to the host simulation. The thermal conductivity example illustrates how a unit agnostic model may still require conversion of inputs or outputs by the host simulation.

6.4.11 Component Indicating Specific Axis, Coordinate Component or Reference

The last component is the specific axis, coordinate component or reference used within the coordinate system (coordinate systems are defined in Section 5). It may also indicate elements of vectors and arrays. It is separated from the units by an underscore (_). As can be seen in the examples, this component is appended last to keep the naming convention consistent for variables that are scalars or vectors. If the coordinate system is included in the name, the specific axis or reference should also be included.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 112 of 343 |

Standard axes selector sets are:

- a) (X, Y, Z) for linear/translational motion,
- b) (X, Y, Z), (Roll, Pitch, Yaw) or (First, Second, Third) for angular motion.

When the specific axis or reference can logically be a vector or an array, the vector or array component may be convenient for a specific implementation. When coordinate system vectors are used, a right-handed triad in order (X, Y, Z) shall be used to avoid confusion. Due to differences between 0- and 1-based array indexing in various implementation languages, use of numerical indices is discouraged.

In the following examples, z would be defined as a constant of either 2 or 3 depending on the implementation language array indexing convention.

Variable name examples:

| | |
|---|--|
| <code>x_bodyAngularRate_rad_s_Roll</code> <code>x_bodyAngularRate_rad_s[Roll]</code> <code>x_bodyAngularRate_rad_s.Roll</code> | Here <code>body</code> is the coordinate system and <code>roll</code> is the specific axis in the body coordinate system, <code>roll</code> indicating angular motion. Examples show alternate scalar and vector implementations and implementation as a structure. NOTE In this example the variable is designated as a state. |
| <code>bodyTurbulenceVelocityWrtGe_ft_s_Z</code> (standard) <code>bodyTurbulenceVelocityWrtGe_ft_s[Z]</code> <code>bodyTurbulenceVelocityWrtGe_ft_s.Z</code> | Here <code>body</code> is the coordinate system and <code>Z</code> is the specific axis in the body coordinate system, <code>Z</code> indicating vertical translational motion. |
| <code>geVelocity_m_s_Y</code> | Here <code>ge</code> is the coordinate system and <code>Y</code> is the specific axis, also indicating translational motion. |
| <code>runway22VelocityOfLeftWheelWrtTd_ft_s_Z</code> | where <code>runway22</code> is the coordinate system (user defined) and <code>Z</code> is the specific axis, also indicating translational motion. <code>LeftWheel</code> is the point on the vehicle and <code>Td</code> (touchdown point) is the reference point. |
| <code>bodyAccelOfPilotEyeWrtEi_m_s2_Y</code> | Here <code>body</code> is the coordinate system and <code>Y</code> is the specific axis, also indicating translational motion. Design pilot eyepoint location is the point on the vehicle. |
| <code>bodyProductOfInertia_slugf2_YZ</code> | Here, <code>_YZ</code> selects the element in the second row and third column of the inertial matrix. |


6.5 Additional Discussion

Very rarely, if ever, are all 10 components of a name used. In the case of

`x_bodyAngularRate_rad_s_Roll`

the following five components were used:

1. prefix (`x_`) indicating that in this formulation of the equations of motion this variable is a state,

| | | | |
|---|---|---|----------------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 113 of 343 |

2. coordinate or reference system (`body`),
3. core name (`AngularRate`),
4. units suffix (`rad_s`), for radians per second
5. specific axis or reference (`Roll`).

In this case "variable source domain" was omitted because `x_bodyAngularRate_rad_s_Roll` is a single quantity defined by the laws of physics; there should not be separate body rates associated with aerodynamics and a propulsion system. If, however, the user wanted to have a multi-body simulation, logically the "variable source domain" could be used to discriminate between different elements of the body, or, perhaps more logically, an array or structure would be used to define different elements in a multi-body or flexible structure problem.

The `Of`, `Wrt`, and `ObsFr` were omitted because the variable is describing motion about (`Of`) the CM and relative to the locally-level coordinate system. Recall that `Wrt` defaults to the locally-level frame for rotational motion and rotational motion variables do not allow specification of an observer's (`ObsFr`) coordinate system.

An `IC` flag is not present, indicating that this variable does not specify an initial condition.

The intent of these conventions is to provide clear communication when exchanging models, not to force the universal use of these variable names. `x_bodyAngularRate_rad_s_Roll` is intended to be a clear, brief, unambiguous name for the variable.

6.5.1 Discarded Conventions and Reasons

One convention considered eliminated the units suffix when the units were from a standard set, but this concept was discarded since always having the units associated with the variable name should help the developer maintain consistent units in the simulation and to reduce programming errors due to improper mixing of units. Consistent application of units in variable names should also reduce the software maintenance effort when a subsequent developer is trying to understand the code to make bug fixes, implement enhancements, or reuse the code.

6.5.2 Relationship with Markup Grammar, DAVE-ML


At present, this variable naming convention is targeted for use with the DAVE-ML XML grammar for model exchange (see Section 7). In DAVE-ML, the dynamic equation formulation prefix and the units suffix are stored as separate components (attributes or child elements) of the variable definition. Thus, including these in a variable name encoded in DAVE-ML would be redundant and a potential source of conflicting information.

The recommended practice is therefore to strip these components (the prefix and suffix) from the variable name when encoding to DAVE-ML, and reinsert them into the variable name if code or model data is generated from the DAVE-ML. Following this convention has two advantages.

- 1) The DAVE-ML grammar does not enforce naming rules; for those variables that do not conform to the naming convention and therefore do not have state/state derivative designation or units, DAVE-ML encourages the inclusion of this information to assist with the clear documentation of a model.
- 2) The convention allows XML processors to adopt the practice of automatically stripping and adding the prefix and suffix to the variable names, reducing the possibility of human error during translation.

6.6 Standard Variable Name Table Example

Using the conventions discussed above, a set of standard variable names has been created. These are

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 114 of 343 |

presented in Annex A. An excerpt of Annex A is given in Table 4 for illustrative purposes.

Interpretation of the standard variable name annex is best given by example. Table 4 presents the standard variable defining the roll Euler angle, its axis system and positive sign convention (positive is RWD, or right wing down). Four name examples are provided. The table includes:

- 1) The symbol for that variable, Φ
- 2) The short name, `PHI` - the short name is included to accommodate standard variable definitions for legacy compilers with significant name length restrictions
- 3) One or more full names using the standard units conventions — generally, one full name with American convention units and one with SI units. Refer to section 6 for a list of the standard units and their abbreviations.

NOTE: While the variable naming convention described in Section 6 encourages the use of the <variable domain> component, this Annex does not include variable domains as part of the normative standard names. This is because the variable domain is normally dependent upon the simulation architecture, and as such is immaterial to the exchange of a simulation model unless the exchange is between facilities with similar architectures.

NOTE: Any suitable units may be used. In the example for `eulerAngle_Roll` both the `_deg` for degrees and the `_rad` for radians are given. The "Full Variable Name" column does not necessarily provide all acceptable units for each variable.

- 4) A description of the variable, if applicable should always specify the coordinate system. Refer to section 5 for a description of the standard coordinate systems.
- 5) The POSITIVE sign convention of the variable — RWD indicates that positive `eulerAngle_Roll` is right wing down. (See section A.2.1 for a list of sign convention acronyms)
- 6) Minimum value, normally only specified for angles
- 7) Maximum values of the variable, normally only specified for angles

In addition this example also illustrates the pitch and yaw Euler angles.


Since roll, pitch and yaw may also conveniently be expressed as an array, the first variable name in Table 4 is the standard definition of the Euler angle array. Again, `eulerAngle_rad(3)` would be the standard array using radians as the units and is fully compliant with the standard.

Euler angles are used in virtually any air vehicle simulation. While normally the coordinate system would be included in the name, it was not included due to the universal definition of Euler angles. A more rigorous name would be `llEulerAngleOfBodyWrtLl_deg(3)` which expresses all the defaults (the variable is the Euler angles of the body with respect to the locally level [11] coordinate system and is presented in [or measured in] the locally level coordinate system). Aircraft simulations typically use Euler angles defined via the 3-2-1 angle rotation sequence (yaw, pitch, roll); other rotation sequences may be used but should be explicitly identified as in `EulerAngle313`, for example.

The standard allows use of any of the standard set of units (degrees or radians in this case).

Table 4 — Standard variable name table excerpt

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Min Value | Max Value |
|-------------------------------------|------------|--|---|--------------------------|-----------|-----------|
| Vehicle Positions and Angles | | | | | | |
| $\underline{\epsilon}$ | EUL(3) | <code>eulerAngle_deg(3)</code> <code>eulerAngle_rad(3)</code> | Array of the ownship roll, pitch, and yaw Euler angles comprised of the elements defined below. LL (locally level) coordinate system. | | | |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 115 of 343 |

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Min Value | Max Value |
|----------|------------|--|---|--------------------------|---------------|-------------|
| Φ | PHI | eulerAngle_deg_Roll eulerAngle_rad_Roll | Roll Euler Angle, LL coordinate system. | RWD | -180, $-\pi$ | 180, π |
| θ | THET | eulerAngle_deg_Pitch eulerAngle_rad_Pitch | Pitch Euler Angle, LL coordinate system | ANU | -90, $-\pi/2$ | 90, $\pi/2$ |
| ψ | PSI | eulerAngle_deg_Yaw eulerAngle_rad_Yaw | Yaw Euler Angle, LL coordinate system | ANR | -180, $-\pi$ | 180, π |

6.7 Summary

While it is recommended that this naming convention be adopted for defining future variables, the real key to a standard variable name is not the name, but the definition of the name. To exchange information between two or more organizations, the most important factor is not whether a variable is named "airspeed" or "VRW," but that there exists a precise, unambiguous definition of the variable (true, indicated, or calibrated airspeed, etc.), including units and coordinate system.

Using the standard variable name simply provides a common language and set of definitions within which to facilitate transfer of the model.


The simulation community is encouraged to propose additional standard variable names. Annex C describes the web site used to support this standard. There is an appropriate URL or email address for submitting additional names or for recommending clarification of existing names.

6.8 References

Stevens, Brian L., and Lewis, Frank L., **Aircraft Control and Simulation, Second Edition**, ISBN 978-0-471-37145-8, 2004, New York, J. Wiley and Sons, 2003.

International Organization for Standardization, *Quantities and units - General*, ISO 80000-1, First edition, 2009-11-15

United States of America Standards Institute: *USA Standard Code for Information Interchange*, USAS X3.4-1967, 1967-07-07

| | | | |
|---|---|--|------------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 116 of 343 |

7 Standard Simulation Data Format and XML Implementation of the Standard: DAVE-ML

7.1 Purpose

This section explains the requirements that a standard simulation data format must be able to satisfy. It includes the content of defined functions and configuration management of the content. The definition of the DAVE-ML format includes data for these components.

This document also discusses conceptually how a data table should be accessed in an executable program.

The standard is implemented in XML as specified by DAVE-ML. Annex B is the current version of the DAVE-ML reference document. Annex C provides links to example programs for loading and looking up data conforming to the XML standard.

7.2 Philosophy

Probably the greatest benefit of the standard to the simulation discipline is the definition of formats for the interchange of tabular data. Tabular data is used widely for non-linear function representation of aerodynamic, engine, atmospheric, and many other model parameters. The simplified interchange of such data should improve efficiency in the simulation community.

Most simulation developers and users have addressed this issue locally. In many simulation communities, a family of tools has been built around existing local function table formats. The intent of this standard is not to replace these local standards, but rather to define a format for communication that will allow each site to develop a single format converter to and from their local format. The DAVE-ML data representation is proposed as an exchange standard.

7.3 Design Objective

The first design objective of the standard data table format was to include all relevant information about real multi-dimensional functions, not just the data values. In the general case of a multi-dimensional table, the independent variables have different numbers of breakpoints, different breakpoints, and different valid ranges, which are all relevant to consistent evaluation of the function.


An equally important design objective was to allow the table to contain information on the data source (provenance, via reference), and a confidence interval for the data. Uses of confidence intervals within a model include direct computation of output confidence levels, estimation of output confidence intervals through Monte Carlo simulations, and mathematically combining different estimates of the same parameter at the same input values. Therefore, confidence statistics should be included when updating an existing or creating a new data set. DAVE-ML allows different types of confidence intervals, not all of which can be meaningfully combined.

The data format must also be easily read by computer or human, and be as self-documenting as possible.

7.4 Standard Function Table Data — An Illustrative Example

Figure 4 presents a fairly standard three-dimensional set of aerodynamic data typical of flight test or wind tunnel results. In the example, lift coefficient is a function of angle-of-attack, Mach number, and a control surface position. More generally stated, the function output (dependent variable) CLALFA is dependent on three inputs (independent variables): `angleOfAttack_deg`, `mach`, & `controlSurfacePos_deg_avgElevator`.

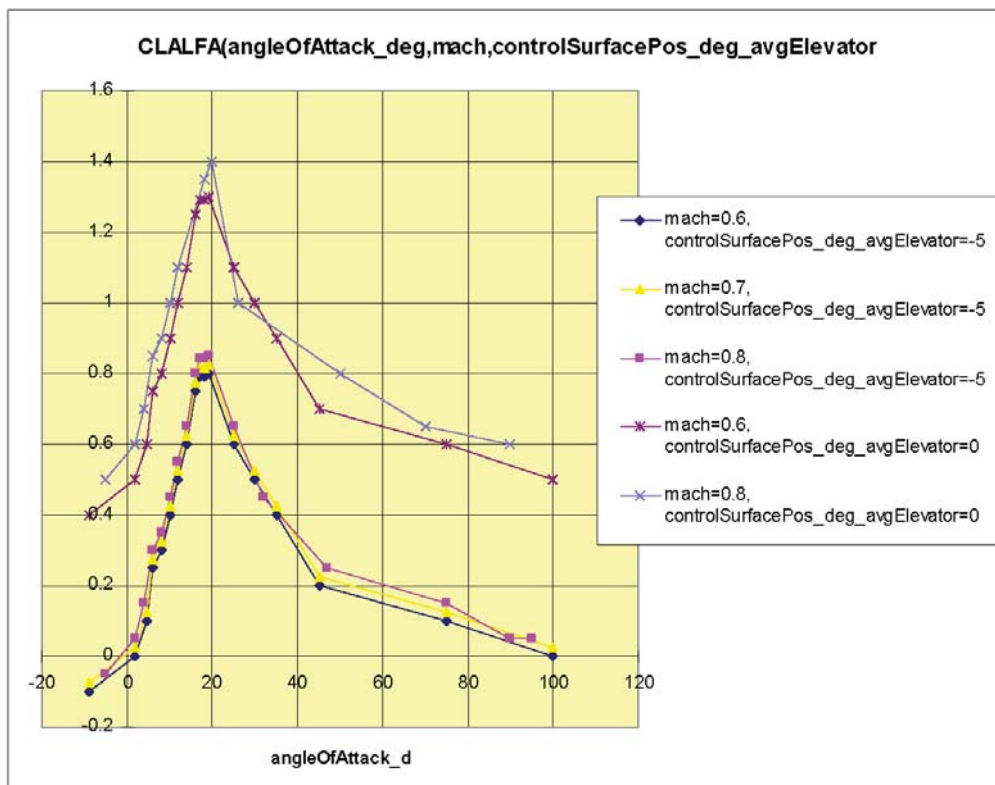
The example illustrates the following characteristics.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | |
| | | | Page #: 117 of 343 |

- 1) The number of breakpoints may be different for each independent variable. Data is presented for a different number of angle-of-attack (`angleOfAttack_deg`) points at each combination of Mach number (`mach`) and control position (`controlSurfacePos_deg_avgElevator`). For the first combination of Mach number and control position (`mach` = 0.6, `controlSurfacePos_deg_avgElevator` = 5) there are 17 angle-of-attack points. For the last combination of Mach number and control position (`mach` = 0.8, `controlSurfacePos_deg_avgElevator` = 0) there are 12 angle-of-attack points. There are also different numbers of Mach number points for each control position. The standard requires this to be represented as an ungridded table.

In contrast, a gridded table would require a function value be defined for every combination of a fixed set of Mach, angle-of-attack and control position breakpoint values.

- 2) At some breakpoints, the values of the other independent variables are different. Again, this is a characteristic of an ungridded table.
- 3) The valid ranges of the independent variables are different, another ungridded table characteristic.
- 4) The above three differences are not consistent for all data. For example, in the sample table the `angleOfAttack_deg`, breakpoints for `mach` = 0.6 and `mach` = 0.7 and for `controlSurfacePos_deg_avgElevator` = -5 are identical.




| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 118 of 343 |

Figure 4 — An illustration of a three-dimensional function table

For function data there is other information that is of importance to the user, without which the data is not very useful. In general this information is as follows.

- Where did the data come from? For example what wind tunnel test or computational model?
- How is it defined? For example, is this at a specific altitude? What is the vehicle configuration ?
- What are the engineering units of the output (the dependent variable) and the independent variables?
- What is the sign convention of the independent and dependent variables? For example, is the control position positive trailing edge up or trailing edge down? Exactly which control surface is it?
- Who created the table? Not where the data came from, but what person decided that this was the correct data for this table?
- How has it been modified and for what reason?
- How accurate is the data estimated to be? Or, mathematically what is the confidence interval of the data?
- By what method is the data intended to be interpolated? For example, linear interpolation or cubic spline interpolation?
- By what method is the data intended to be extrapolated when the independent variable values are outside the specified range for the breakpoint data?

The DAVE-ML grammar has data elements that contain all of the above information. It also includes the ability to automate static checks of the function data to allow spot checking of the function after it has been exchanged. It is discussed in detail in the DAVE-ML reference document contained in Annex B. An introduction and overview of DAVE-ML's seven major elements is provided here.

7.5 DAVE-ML Major Elements (Annex B)

The major elements of DAVE-ML are listed below in the order required by the DAVE-ML DTD. The root element of a DAVE-ML model file, *DAVEfunc*, can have several sub-elements and attributes; most attributes and sub-elements are optional. The only sub-elements a DAVE-ML file must contain are the *fileHeader* and at least one *variableDef*.

Information (breakpoints, data points, provenance, etc.) that is used by more than one major element should be defined once and then referenced in any subsequent use.


The sub-elements must appear in the following order (as required by the DTD):

fileHeader — states the source and purpose of the file. It must include the author's contact details and the file creation date, and may include a description, reference information, and modification history.

variableDef — each *variableDef* defines one of the constants or signals (variables) used in the DAVE-ML model, whether input, output or internal. The definition includes all the attributes and sub-elements required to fully characterize the variable of interest, including a MathML definition if the variable's value is equation-based. Standard variables as defined in Section 6 and Annex A are encouraged here.

breakpointDef — defines breakpoint sets to be used in the model. The breakpoints are the coordinate values along one axis of a gridded linear function value table. One *breakpointDef* may be reused by several functions.

griddedTableDef — defines an orthogonally-gridded multi-dimensional table of the values of a

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 119 of 343 |

function at the intersection of a set of specified independent inputs (breakpoints). The coordinates along each dimension are defined in separate *breakpointDef* elements.

ungriddedTableDef — defines a table of non-orthogonal values of a function, each with the values of their independent coordinates.

function — defines a function by connecting independent variables, breakpoints and data tables to their output value.

checkData — contains one or more input/output vector pairs (and optionally a vector of internal values) for the encoded model to assist in verification and debugging of the implementation.

Annex B contains the latest version of the DAVE-ML reference document, including a detailed description and examples of the data element definitions of the DAVE-ML standard. Section 8 of Annex B provides detailed XML element references and descriptions.

7.6 Simple DAVE-ML Examples

The easiest way to understand the standard is through an example. Annex B contains many more examples of the DAVE-ML implementation of the standard.

A simple one dimensional relationship example, giving pitching moment coefficient as a function of angle of attack, is shown in Table 5 and Figure 5.

Table 5 — A simple one-dimensional function table

| angleOfAttack deg | 0 | 18 | 19 | 20 | 22 | 23 | 25 | 27 | 90 |
|-----------------------|-----|------|-------|-------|-------|-------|-------|-------|------|
| cm(angleOfAttack deg) | 0.1 | -0.1 | -0.09 | -0.08 | -0.05 | -0.05 | -0.07 | -0.15 | -0.6 |

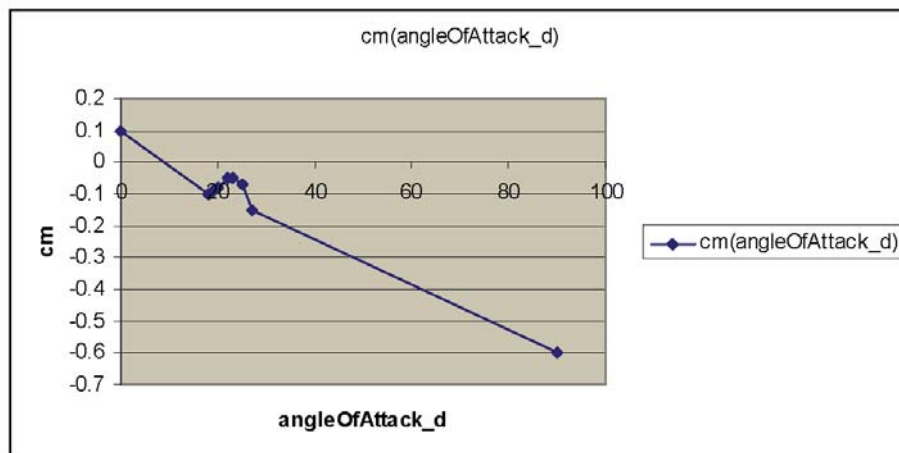



Figure 5 — A simple one-dimensional gridded function

A DAVE-ML implementation for this function could be as follows.

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<!DOCTYPE DAVEfunc PUBLIC "-//AIAA//DTD for Flight Dynamic Models - Functions
2.0//EN" "DAVEfunc.dtd">
<DAVEfunc xmlns="http://daveml.org/2010/DAVEML">

  <!-- ===== -->
  <!--===== File Header Components ===== -->
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 120 of 343 |

```

<!-- ===== -->
<fileHeader>

<!-- This is an example of the file header components of the
derivative of Cm as a function of angle of attack. It must
define all documents that are later referenced by any function.

Note that there is not much information in this header,
because it is meant to be a simple example. In
reality, probably the most important information is the
author, the reference and the modification record, because
these data describe where the data came from and if it has
been changed (and how). See annex B for more complete
examples.
-->

<author name="Bruce Hildreth" org="JFTI" email="bhildreth@jfti.com"/>
<fileCreationDate date="2006-03-18"/>
<description>
  This is made up data to use as an example of a simple gridded function.
</description>
<reference refID="BLHRpt1" author="Joe Smith"
  title="A Generic Aircraft Simulation Model (does not really exist)"
  accession="ISBN 1-2345-678-9" date="2004-01-01"/>

<!-- no modifications so far, so we don't need a modificationRecord yet -->

</fileHeader>

<!-- ===== -->
<!--===== Variable Definition Components ===== -->
<!-- ===== -->

<!-- Input variable -->

<variableDef name="Angle of attack" varID="angleOfAttack" units="deg" >
  <isStdAIAA/> <!-- Indicates that this variable is a standard
    variable, which is why the author omitted
    description and sign convention
    and any other info. (it certainly could
    be included here) -->
</variableDef>

<!-- Output (function value) -->


<variableDef name="Pitching moment coefficient due to angle of attack"
  varID="CmAlfa" units="nondimensional" sign="+ANU">
  <description>
    The derivative of total pitching moment with respect to
    angle of attack.
  </description>
</variableDef>

<!-- ===== -->
<!--===== Breakpoint Definition Set ===== -->
<!-- ===== -->

<breakpointDef bpID="angleOfAttack_bp1">

<!--

```

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 121 of 343 |

Note that the bpID can be any valid XML string to uniquely identify the breakpoints. The author here chose to use a name related to the independent variable that is expected to be used to look up the function. In fact, if this set of breakpoints were shared by many functions and different independent variables would be used to look up the function, then the bpID of "angleOfAttack_bp1" would be misleading and a more generic name like "AOA" would probably be better.

-->

```
<description>
Angle of attack breakpoint set for CmAlfa, CdAlfa, and ClAlfa
</description>
```

```
<bpVals> <!-- Always comma separated values -->
0, 18, 19, 20, 22, 23, 25, 27, 90
</bpVals>
```

```
</breakpointDef>
```

```
<!-- ===== -->
<!--===== Gridded Table Definition ===== -->
<!-- ===== -->
```

```
<griddedTableDef gtID="CmAlfa_Table1">
<description>
The derivative of Cm wrt fuselage AOA in degrees
</description>
```

```
<provenance>
<author name="Jake Smith" org="AlCorp"/>
<functionCreationDate date="2006-12-31"/>
<documentRef refID="BLHRpt1" /> <!-- This points back to the Header,
which provides the information
about BLHRpt1. -->
</provenance>
```

```
<breakpointRefs>
<bpRef bpID="angleOfAttack_bp1" />
</breakpointRefs>
```


```
<uncertainty effect="percentage">
<normalPDF numSigmas="3">
<bounds>12</bounds>
</normalPDF>
<!-- This means that the 3 sigma confidence is +-12% on the Data. -->
</uncertainty>
```

```
<dataTable> <!-- Always comma separated values -->
0.1,-0.1,-0.09, -.08, -0.05, -0.05, -0.07, -0.15, -0.6
</dataTable>
```

```
</griddedTableDef>
```

```
<!-- ===== -->
<!--===== Function Definition ===== -->
<!-- ===== -->
```

```
<!-- The function definition ties input and output variables
with table definitions. This allows a level of abstraction such
that the table, with its breakpoint definitions, can be reused
```


| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 122 of 343 |

```

    by several functions (such as left and right aileron or multiple
    thruster effect tables).
-->


<function name="Cm_alpha_func">
  <description>
    Variation of pitching moment coefficient with angle of attack (example)
  </description>
  <independentVarRef varID="angleOfAttack"/>
  <dependentVarRef varID="CmAlfa"/>
  <functionDefn>
    <griddedTableRef gtID="CmAlfa_Table1"/>
  </functionDefn>
</function>

<!-- ===== -->
<!--===== Check Data Cases ===== -->
<!-- ===== -->

<!-- Checkcase data provides automatic verification of the model by
specifying the tolerance in output values for a given set of
input values. One 'staticShot' is required per input/output
mapping; in this case for a single input, single output model,
we have a single input signal and a single output signal in each
test point.
-->

<checkData>
  <staticShot name="case 1">
    <checkInputs>
      <signal>
        <varID>angleOfAttack</varID>
        <signalValue> 0.</signalValue>
      </signal>
    </checkInputs>
    <checkOutputs>
      <signal>
        <varID>CmAlfa</varID>
        <signalValue>0.01</signalValue>
        <tol>0.00001</tol>
      </signal>
    </checkOutputs>
  </staticShot>
  <staticShot name="case 2">
    <checkInputs>
      <signal>
        <varID>angleOfAttack</varID>
        <signalValue> 5.</signalValue>
      </signal>
    </checkInputs>
    <checkOutputs>
      <signal>
        <varID>CmAlfa</varID>
        <signalValue>0.04444</signalValue>
        <tol>0.00001</tol>
      </signal>
    </checkOutputs>
  </staticShot>
  <staticShot name="case 3">
    <checkInputs>
      <signal>
        <varID>angleOfAttack</varID>
        <signalValue>10.</signalValue>


```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 123 of 343 |

```

    </signal>
  </checkInputs>
<checkOutputs>
  <signal>
    <varID>CmAlfa</varID>
    <signalValue>-0.01111</signalValue>
    <tol>0.00001</tol>
  </signal>
</checkOutputs>
</staticShot>
<staticShot name="case 4">
  <checkInputs>
    <signal>
      <varID>angleOfAttack</varID>
      <signalValue>15.</signalValue>
    </signal>
  </checkInputs>
  <checkOutputs>
    <signal>
      <varID>CmAlfa</varID>
      <signalValue>-0.06667</signalValue>
      <tol>0.00001</tol>
    </signal>
  </checkOutputs>
</staticShot>
<staticShot name="case 5">
  <checkInputs>
    <signal>
      <varID>angleOfAttack</varID>
      <signalValue>20.</signalValue>
    </signal>
  </checkInputs>
  <checkOutputs>
    <signal>
      <varID>CmAlfa</varID>
      <signalValue>-0.08</signalValue>
      <tol>0.00001</tol>
    </signal>
  </checkOutputs>
</staticShot>
<staticShot name="case 6">
  <checkInputs>
    <signal>
      <varID>angleOfAttack</varID>
      <signalValue>25.</signalValue>
    </signal>
  </checkInputs>
  <checkOutputs>
    <signal>
      <varID>CmAlfa</varID>
      <signalValue>-0.07</signalValue>
      <tol>0.00001</tol>
    </signal>
  </checkOutputs>
</staticShot>
<staticShot name="case 7">
  <checkInputs>
    <signal>
      <varID>angleOfAttack</varID>
      <signalValue>50.</signalValue>
    </signal>
  </checkInputs>
  <checkOutputs>
    <signal>

```

| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 124 of 343 |

```

    <varID>CmAlfa</varID>
    <signalValue>-0.31429</signalValue>
    <tol>0.00001</tol>
  </signal>
</checkOutputs>
</staticShot>
</checkData>
</DAVEfunc>

```

While the above seems excessively long for a function with only 9 data points, most of its content involves self-documentation and checking. Therefore, as well as the function's data it includes the data's units, coordinate systems, uncertainty descriptions and provenance. It also includes many instructional comments, and verification data for multiple simulation conditions. Also, a very large complex function would only be expanded by the additional data points. The definitions and provenance information included with the function would probably not change much.

In the minimum, the same nominal data can be represented as shown. It is also possible to completely remove all whitespace between elements for more compactness, but this greatly affects readability by humans.

```

<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<!DOCTYPE DAVEfunc PUBLIC "-//AIAA//DTD for Flight Dynamic Models - Functions
2.0//EN" "DAVEfunc.dtd">
<DAVEfunc xmlns="http://daveml.org/2010/DAVEML">
  <fileHeader>
    <author name="Bruce Hildreth" org="SAIC"/>
    <fileCreationDate date="2006-03-18"/>
  </fileHeader>
  <variableDef name="Angle of attack" varID="angleOfAttack"
units="deg"/>
  <variableDef name="CmAlpha" varID="CmAlfa" units=""/>
  <breakpointDef bpID="angleOfAttack_bp1">
    <bpVals> 0, 18, 19, 20, 22, 23, 25, 27, 90 </bpVals>
  </breakpointDef>
  <griddedTableDef gtID="CmAlfa_Table1">
    <breakpointRefs>
      <bpRef bpID="angleOfAttack_bp1"/>
    </breakpointRefs>
    <dataTable> 0.1,-0.1,-0.09, -.08, -0.05, -0.05, -0.07, -0.15, -0.6
  </dataTable>
  </griddedTableDef>
  <function name="Cm_alpha func">
    <independentVarRef varID="angleOfAttack"/>
    <dependentVarRef varID="CmAlfa"/>
    <functionDefn>
      <griddedTableRef gtID="CmAlfa_Table1"/>
    </functionDefn>
  </function>
</DAVEfunc>

```

The other principal means of model representation in DAVE-ML is through Math-ML elements, which are used to specify calculations.

For example:


$$\text{totalThrust_N} = \text{engine1Thrust_N} + \text{engine2Thrust_N} + \text{engine3Thrust_N}$$

This equation, which is part of the model being exchanged, may be encoded in DAVE-ML and exchanged as data as shown below.

```

<?xml version="1.0" encoding="UTF-8" standalone="no"?>

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 125 of 343 |

```


<!DOCTYPE DAVEfunc PUBLIC "-//AIAA/DTD for Flight Dynamic Models - Functions
2.0//EN" "DAVEfunc.dtd">
<DAVEfunc xmlns="http://daveml.org/2010/DAVEML">
  <fileHeader>
    <author name="Dan Newman" org="Quantitative Aeronautics"/>
    <creationDate date="2009-11-10"/>
    <description>
      Simple MathML example : total thrust is the sum of three inputs.
    </description>
  </fileHeader>
  <variableDef name="Engine #1 thrust" varID="engine1Thrust" units="N"/>
  <variableDef name="Engine #2 thrust" varID="engine2Thrust" units="N"/>
  <variableDef name="Engine #3 thrust" varID="engine3Thrust" units="N"/>
  <variableDef name="Total thrust" varID="totalThrust" units="N" >
    <calculation>
      <math>
        <apply>
          <plus/>
            <ci>engine1Thrust</ci>
            <ci>engine2Thrust</ci>
            <ci>engine3Thrust</ci>
          </apply>
        </math>
      </calculation>
    </isOutput>
  </variableDef>
</DAVEfunc>

```

7.7 Summary

The DAVE-ML implementation of the standard enables nearly effortless transfer of simulation aerodynamics models between simulation facilities or architectures. Inclusion of Math-ML elements allows the formulation of algebraic equations, such as aerodynamic, propulsion, inertial, landing gear or control system models, to be included as data in the model. DAVE-ML is also suitable for use or transfer of tabular functions and algebraic equations for any type of data, not just simulation models.

While the above paragraphs provide an overview of the concepts implemented in DAVE-ML, Annex B is the normative authority for this standard. It includes much more detail and examples on how to easily build a DAVE-ML compliant simulation. Annex C provides a reference to the DAVE-ML web site, which includes tools that facilitate use of DAVE-ML based models in many applications.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 126 of 343 |

8 Future Work

The AIAA Modeling and Simulation Technical Committee plans to continue its efforts in facilitation of the exchange of simulations and models throughout the user community. Comments and suggestions on this expansion are welcomed on the simulation standards discussion group. Visit <http://www.daveml.org> for submittal information. The following sections describe the two tasks of primary interest.


8.1 Time History Information

The immediate task that is being pursued is the transfer of validation data between facilities. This is for the purpose of sending time response validation data when a model is exchanged.

The approach being taken is to adopt a flight test data standard. This has the advantage of using an existing standard and facilitating the use of flight test data to validate a simulation. Lockheed Martin has an existing internal standard that they have released for use by the community. It is implemented in hierarchical data format (HDF) and has been adopted by the JSF community and other programs. It is the Modeling and Simulation Technical Committee's intent to adopt this for the transfer of simulation validation data. Some work will be required to define the data elements that are required for the validation of a simulation. This is expected to be a subset of the data elements that comprise flight test data.

8.2 Dynamic Element Specification

The addition of the specification of dynamics (e.g. continuous and discrete states) is being considered to expand the scope of the standard. This expansion would allow more of the domain of a flight vehicle model (flight controls as a good example) to be exchanged in a non-proprietary, facility-neutral way.


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 127 of 343 |

9 Conclusion

This is a standard for the purpose of facilitating the exchange of simulation models between users. This purpose cannot be emphasized enough. It is not meant to enforce any standard simulation architecture. DAVE-ML provides the mechanism for exchange of the modeling data and equations; the standard variables and coordinate systems provide a common language to facilitate effective communication. The standard is also valuable for documenting a model, since the names and coordinate system definitions are clearly documented for the user.


A model can be DAVE-ML compliant without using any standard names or coordinate systems, but the exchange of such a model between users will be more difficult, since clear definitions will have to be exchanged also.

It is the earnest desire of the authors of this standard that the user community will employ the current standard for aerodynamic models, continue to suggest improvements to the standard, and develop tools to enhance the standard. <http://www.daveml.org> contains information on how to be part of this effort and/or submit change or improvement recommendations.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 128 of 343 |

10 Standard Variable Names (Normative)

(Now a separate .doc for ease of editing)

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 129 of 343 |

ANSI/AIAA
Annex A. Standard Variable Names

S-119

Standard Variable Names (Normative)

A.1 General

The standard variable naming convention is described in detail in Section 6. The table in this annex contains a set of standard simulation variables that are independent of the particular vehicle type being simulated. Use of these standard variables provides a "standard language" which will facilitate the communication of the information required to exchange simulation models. These variables are tailored towards aircraft simulation and to a lesser extent, spacecraft. Visit <http://DaveML.org> to suggest additional variables or changes to the existing list.

A.2 Table Explanation

Interpretation of the standard variable name table is best given by example. In general the table has 7 columns. These are described below using the `eulerAngle_Roll` as an example:

- 1) The symbol for that variable, Φ
- 2) The short name, PHI
- 3) One or more full names using the standard units conventions — generally, one full name with American convention units and one with SI units. Refer to section 6 for a list of the standard units and their abbreviations.

NOTE: While the variable naming convention described in Section 6 encourages the use of the <variable domain> component, this Annex does not include variable domains as part of the normative standard names. This is because the variable domain is normally dependent upon the simulation architecture, and as such is immaterial to the exchange of a simulation model unless the exchange is between facilities with similar architectures.

NOTE: Any suitable units may be used. In the example for `eulerAngle_Roll` both the `_deg` for degrees and the `_rad` for radians are given. The "Full Variable Name" column does not necessarily provide all acceptable units for each variable.

- 4) A description of the variable, if applicable should always specify the coordinate system. Refer to section 5 for a description of the standard coordinate systems.
- 5) The POSITIVE sign convention of the variable — RWD indicates that positive `eulerAngle_Roll` is right wing down. (See section A.2.1 for a list of sign convention acronyms)
- 6) Minimum value, normally only specified for angles
- 7) Maximum values of the variable, normally only specified for angles


Note:

This example also illustrates the pitch and yaw Euler angles.

Some variables may be used to represent variables referenced to more than one coordinate system. In this case the coordinate system is specified as `xx` and any coordinate system reference (refer to the body of this standard) may be substituted for the `xx`. For example, `xxVelocity_ft_s_Y` may represent:

`eiVelocity_ft_s_Y` for the velocity along the Y axis of the ei coordinate system - Earth centered Inertial (also known as geocentric inertial) coordinate system

`geVelocity_ft_s_Y` for the velocity along the Y axis of the geocentric Earth (ge) coordinate system. Also referred to as the Earth Centered Earth Fixed (ECEF coordinate system).

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 130 of 343 |

ANSI/AIAA

S-119

Annex A. Standard Variable Names


voVelocity_ft_s_Y for the vo coordinate system (Vehicle carried, Orbit defined coordinate system)

Roll, pitch and yaw may also conveniently be expressed as an array. Again, eulerAngle_rad[3]¹ would be the standard array using radians as the units and is fully compliant with the standard.

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Min Value | Max Value |
|-----------------|------------|--|---|--------------------------|----------------|-------------|
| \underline{g} | EUL[3] | eulerAngle_deg[3] eulerAngle_rad[3] | Array of the roll, pitch, and yaw Euler angles comprised of the elements defined below. LL (locally level) coordinate system. | | | |
| Φ | PHI | eulerAngle_deg_Roll eulerAngle_rad_Roll | Roll Euler Angle, LL coordinate system. | RWD | -180, - π | 180, π |
| θ | THET | eulerAngle_deg_Pitch eulerAngle_rad_Pitch | Pitch Euler Angle, LL coordinate system | ANU | -90, - $\pi/2$ | 90, $\pi/2$ |
| Ψ | PSI | eulerAngle_deg_Yaw EulerAngle_rad_Yaw | Yaw Euler Angle, LL coordinate system | ANR | -180, - π | 180, π |

The variable name table below does not specify which variables are states, state derivatives, inputs, disturbances, simulation controls or initial conditions. These specifications may be added to any appropriate variable. Refer to Section 4.2 in the body of this standard for use of dynamic equation prefixes and section 6.4.8 for initial condition specification.

¹ A number or pair of numbers between square brackets represents the number of elements in an array or matrix respectively.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 131 of 343 |

ANSI/AIAA
Annex A. Standard Variable Names

S-119


A.2.1 Annex A Acronyms

Positive Sign Convention Acronyms

The following acronyms may appear as values for the "positive sign convention" of variables defined in the variable name tables.

| | |
|-------------|---|
| +X | in the positive direction of the presentation coordinate system's X-axis |
| +Y | in the positive direction of the presentation coordinate system's Y-axis. |
| +Z | in the positive direction of the presentation coordinate system's Z-axis |
| ABV | positive above |
| AFT | positive aft |
| AH | positive above horizon |
| ANR | positive aircraft nose right |
| ANU | positive aircraft nose up |
| BH | positive below horizon |
| BLO | positive below |
| CCFN | positive counterclockwise from north |
| COMP | positive compressed |
| CWFN | positive clockwise from north |
| DEC | decrease |
| DN or Down | positive down |
| E or East | positive East |
| FWD | positive forward |
| INC | positive increase |
| LED | positive leading edge down |
| LT or Left | positive left |
| MAC | percent mean aerodynamic chord |
| N or North | positive North |
| NSC | no sign convention (variable is always positive) |
| OUT | positive outward |
| POS | always positive |
| RT or Right | positive right |
| RTCL | positive right of centerline |
| RWD | positive right wing down |

Annex A Page 3 of 54

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 132 of 343 |

ANSI/AIAA


S-119

Annex A. Standard Variable Names

| | |
|-----|------------------------------|
| TED | positive trailing edge down |
| TEL | positive trailing edge left |
| TER | positive trailing edge right |
| TEU | positive trailing edge up |
| UP | positive up |
| WOW | weight on wheels |

Control Surface and Position Acronyms

| | |
|-----|--------------------|
| LEF | leading edge flap |
| TEF | trailing edge flap |

| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 133 of 343 |

ANSI/AIAA S-119


Annex A. Standard Variable Names

A.3 Standard Variable Name Tables

Table A.1 — Vehicle Positions and Angles

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------------|------------|--|---|--------------------------|---------------|----------------|-------------|
| $\underline{\epsilon}$ | EUL | eulerAngle_deg[3] eulerAngle_rad[3] | Array of the roll, pitch, and yaw Euler angles defined below. LL (locally level) coordinate system. | | | | |
| Φ | PHI | eulerAngle_deg_Roll eulerAngle_rad_Roll | Roll Euler Angle, LL coordinate system. | RWD | | -180, - π | 180, π |
| θ | THET | eulerAngle_deg_Pitch eulerAngle_rad_Pitch | Pitch Euler Angle, LL coordinate system | ANU | | -90, - $\pi/2$ | 90, $\pi/2$ |
| ψ | PSI | eulerAngle_deg_Yaw eulerAngle_rad_Yaw | Yaw Euler Angle, LL coordinate system | ANR | | -180, - π | 180, π |
| $\sin \Phi$ | SPHI | sinEulerAngle_Roll | Sine Of Euler Roll Angle | RWD | | -1.0 | 1.0 |
| $\cos \Phi$ | CPHI | cosEulerAngle_Roll | Cosine Of Euler Roll Angle | RWD | | -1.0 | 1.0 |
| $\sin \theta$ | STHT | sinEulerAngle_Pitch | Sine Of Euler Pitch Angle | ANU | | -1.0 | 1.0 |
| $\cos \theta$ | CTHT | cosEulerAngle_Pitch | Cosine Of Euler Pitch Angle | ANU | | 0.0 | 1.0 |
| $\sin \psi$ | SPSI | sinEulerAngle_Yaw | Sine Of Euler Yaw Angle | ANR | | -1.0 | 1.0 |
| $\cos \psi$ | CPSI | cosEulerAngle_Yaw | Cosine Of Euler Yaw Angle | ANR | | -1.0 | 1.0 |
| $T_{FE/B}$ | T | feToBodyT[3,3] | The FE to Body transformation matrix composed of the elements defined below | | | | |
| $T_{FE/B}[1,1]$ | T11 | feToBodyT11 | CTHT*CPSI (FE To B) coordinate transformation element | | | | |
| $T_{FE/B}[2,1]$ | T21 | feToBodyT21 | SPHI*STHT*CPSI - CPHI*SPSI (FE To B) coordinate transformation element | | | | |

Annex A Page 5 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 134 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-----------------|------------|--|--|--------------------------|---------------|-----------------|---------------|
| $T_{FE/B}[3,1]$ | T31 | feToBodyT31 | CPHI*STHT*CPSI + SPHI*SPSI (FE to B) coordinate transformation element | | | | |
| $T_{FE/B}[1,2]$ | T12 | feToBodyT12 | CTHT*SPSI (FE to B) coordinate transformation element | | | | |
| $T_{FE/B}[2,2]$ | T22 | feToBodyT22 | SPHI*STHT*SPSI + CPHI*CPSI (FE to B) coordinate transformation element | | | | |
| $T_{FE/B}[3,2]$ | T32 | feToBodyT32 | CPHI*STHT*SPSI - SPHI*CPSI (FE to B) coordinate transformation element | | | | |
| $T_{FE/B}[1,3]$ | T13 | feToBodyT13 | -STHT (FE to B) coordinate transformation element | | | | |
| $T_{FE/B}[2,3]$ | T23 | feToBodyT23 | SPHI*CTHT (FE to B) coordinate transformation element | | | | |
| $T_{FE/B}[3,3]$ | T33 | feToBodyT33 | CPHI*CTHT (FE to B) coordinate transformation element | | | | |
| γ | GAMV | flightPathAngle_rad flightPathAngle_deg | Flight Path Angle Above Horizon | ANU | | $-\pi/2$ -90 | $\pi/2$ 90 |
| χ | GAMH | flightPathAzimuth_rad flightPathAzimuth_deg | Flight Path Angle In Horizon Plane, from North | CWFN | | $-\pi$ -180 | π 180 |
| h | ALT | altitudeMsl_ft altitudeMsl_m | Geometric altitude of vehicle altimeter above Mean Sea Level | UP | | | |

Annex A Page 6 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 135 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-----------|-------------|---|---|--------------------------|---------------|-----------|-----------|
| λ | XLON | geLongitude_rad geLongitude_deg Note The coordinate system may be deleted if Ge coordinate system, resulting in longitude_rad longitude_deg | Longitude of Vehicle Cm with respect to the ge (geocentric Earth) coordinate system. | WEST | | | |
| ϕ | XLAT | geLatitude_rad geLatitude_deg Note The coordinate system may be deleted if Ge coordinate system, resulting in latitude_rad latitude_deg | Geodetic Latitude of Vehicle Cm with respect to the ge (geocentric Earth) coordinate system. | NORTH | | | |
| | XLONIM U | geLongitudeOfImu_rad geLongitudeOfImu_deg Note The coordinate system may be deleted if Ge coordinate system, resulting in longitudeOfImu_rad longitudeOfImu_deg | Longitude of Vehicle Imu with respect to the ge coordinate system. This variable does not include any Imu sensor errors. | West | | | |
| | XLATIMU | geLatitudeOfImu_rad geLatitudeOfImu_deg Note The coordinate system may be deleted if Ge coordinate system, resulting in latitudeOfImu_rad latitudeOfImu_deg | Geodetic Latitude of Vehicle Imu with respect to the Ge coordinate system. This variable does not include any Imu sensor errors. | NORTH | | | |

Annex A Page 7 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 136 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|-------------|---|--|--------------------------|---------------|-----------|-----------|
| | | geSensedLongitudeOfImu_rad eSensedLongitudeOfImu_deg Note The coordinate system may be deleted if Ge coordinate system, resulting in sensedLongitudeOfImu_rad sensedLongitudeOfImu_deg | Longitude of Vehicle Imu with respect to the Ge coordinate system. This variable includes any Imu sensor errors. | West | | | |
| | | geSensedLatitudeOfImuWrtZzz_rad geSensedLatitudeOfImuWrtZzz_deg Note The coordinate system may be deleted if Ge coordinate system, resulting in sensedLatitudeOfImu_rad sensedLatitudeOfImu_deg | Geodetic Latitude of Vehicle Imu with respect to the Ge coordinate system. This variable includes any Imu sensor errors. | NORTH | | | |
| | HGT_RW Y | runwayHeightWrtMsl_ft runwayHeightWrtMsl_m | Height Of Runway w.r.t. mean Sea Level | Above | | | |
| | | General Definition xxPositionOfYyyWrtZzz_ft[3] xxPositionOfYyyWrtZzz_m[3] For Example: xxPosition_ft[3] is the same as xxPositionOfCmWrtxx_ft[3] | <p>General Definition for Linear and Angular Positions: Refer to section 6 of this standard for complete guidance on the naming of variables.</p> <p>Vector of positions of Yyy with respect to Zzz (a user defined reference point or coordinate system origin) in the xx coordinate system. The lengths of xx, Yyy, Zzz are not restricted to 2 and 3 characters respectively.</p> <p>The coordinate system xx must always be defined. If the OfYyy is not defined the definition defaults to the vehicle Cm for linear positions and the body coordinate system for angular positions. If the WrtZzz is not defined the reference point defaults to the origin of the xx coordinate system for linear position and the locally level (Ll) coordinate system for angular position.</p> <p>Comprised of the three components as defined below.</p> | | | | |

Annex A Page 8 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 137 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|--|---|-------------------------------|---------------|-----------|-----------|
| | | xxPositionOfYyyWrtZzz_ft_X xxPositionOfYyyWrtZzz_m_X or xxPosition_ft_X | X position of Yyy with respect to Zzz (a user defined reference point) in the xx coordinate system. Defaults to the Cm and origin of the xx coordinate system. | (Yyy - Zzz) | | | |
| | | xxPositionOfYyyWrtZzz_ft_Y xxPositionOfYyyWrtZzz_m_Y or xxPosition_ft_Y | Y position of Yyy with respect to Zzz (a user defined reference point) in the xx coordinate system. Defaults to the Cm and origin of the xx coordinate system. | (Yyy - Zzz) | | | |
| | | xxPositionOfYyyWrtZzz_ft_Z xxPositionOfYyyWrtZzz_m_Z or xxPosition_ft_Z | Z position of Yyy with respect to Zzz (a user defined reference point) in the xx coordinate system. Defaults to the CG and origin of the xx coordinate system. | (Yyy - Zzz) | | | |
| | | fePosition_ft [3] | Vector of positions of the CM in the flat Earth coordinate system. Comprised of the three components as defined below. | | | | |
| | XCG | fePosition_ft_X | X or North position of the CM in the flat Earth coordinate system | | | | |
| | YCG | fePosition_ft_Y | Y or East position of the CM in the flat Earth coordinate system | | | | |
| | ZCG | fePosition_ft_Z | Z or Down position of the CM in the flat Earth coordinate system | minus equals above the ground | | | |
| | | | | | | | |

Annex A Page 9 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 138 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|---|--|---------------|-----------|-----------|
| | | xxPositionOfMrcWrtZzz_ft_X xxPositionOfMrcWrtZzz_m_X | X position of the moment reference center (Mrc) with respect to Zzz in the xx coordinate system. | | | | |
| | | xxPositionOfMrcWrtZzz_ft_Y xxPositionOfMrcWrtZzz_m_Y | Y position of the moment reference center (Mrc) with respect to Zzz in the xx coordinate system. | | | | |
| | | xxPositionOfMrcWrtZzz_ft_Z xxPositionOfMrcWrtZzz_m_Z | Z position of the moment reference center (Mrc) with respect to Zzz in the xx coordinate system. | | | | |
| | REF [3] | bodyPositionOfMrc_ft [3] | Vector of positions of the aerodynamic moment reference center in the body coordinate system. Since the origin of the body coordinate system is the Cm, this vector is the positions of the Mrc with respect to the Cm Comprised of the three components as defined below. | | | | |
| | XREF | bodyPositionOfMrc_ft_X | X position of the Mrc in the body coordinate system | Mrc in front of the origin (Cm) | | | |
| | YREF | bodyPositionOfMrc_ft_Y | Y position of the Mrc in the body coordinate system | Mrc out the right wing with respect to the origin (Cm) | | | |
| | ZREF | bodyPositionOfMrc_ft_Z | Z position of the Mrc in the body coordinate system | Mrc below the origin (Cm) | | | |
| | PLT2CG[3] | bodyPositionOfPilotEyeWrtCm_f [3] bodyPositionOfPilotEyeWrtCm_ft [3] | Vector of positions of the pilot's eye with respect to the Cm in the body coordinate system. Comprised of the three components as defined below. | | | | |
| | XPLT2CG | bodyPositionOfPilotEyeWrtCm_ft_X bodyPositionOfPilotEyeWrtCm_ft_X | X position of pilot eye point w.r.t. Cm, in the body coordinate system | Eye FWD of Cm | | | |
| | YPLT2CG | bodyPositionOfPilotEyeWrtCm_ft_Y bodyPositionOfPilotEyeWrtCm_ft_Y | Y position of pilot eye point w.r.t. Cm, in the body coordinate system | Eye Right of the Cm | | | |

Annex A Page 10 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 139 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------|-------------|---|---|---|---------------|-----------|-----------|
| | ZPLT2C G | bodyPositionOfPilotEyeWrtCm_ft_Z bodyPositionOfPilotEyeWrtCm_ft_Z | Z position of pilot eye point w.r.t Cm, in the body coordinate system | Eye below Cm | | | |
| EXAMPLES | | | | | | | |
| | | runway22Position_ft [3] indicates position of the Cm (default) with respect to the origin of the Runway22 coordinate system (default), in the runway22 coordinate system. A more complete and clear name would be: runway22PositionOfCmWrtRunway22_ft [3] runway22PositionOfFwdLeftMainWheelWrtTd_ft [3] indicates position of the forward left main wheel with respect to the touchdown point in the Runway 22 coordinate system NOTE All coordinate systems are user defined | Vector of positions of the vehicle Cm relative to the Runway 22 (a user defined coordinate system) touchdown reference point. Comprised of the three components as defined below. | | | | |
| | XCGTD | runway22PositionOfCmWrtTd_ft_X runway22PositionOfCmWrtTd_m_X | Cm X-position w.r.t. runway touchdown point in the specified (Runway22) coordinate system. | Cm Down the runway from the reference point | | | |
| | YCGTD | runway22PositionOfCmWrtTd_ft_Y runway22PositionOfCmWrtTd_m_Y | Cm Y-position w.r.t. runway touchdown point in the specified (Runway22) coordinate system. | Cm to the right of the reference point | | | |
| | ZCGTD | runway22PositionOfCmWrtTd_ft_Z runway22PositionOfCmWrtTd_m_Z | Cm Z-position w.r.t. runway touchdown point in the specified (Runway22) coordinate system. (This variable is normally negative.) | Cm below the TD point | | | |
| | RE | smoothEarthRadius_ft smoothEarthRadius_m | Geocentric radius of Earth (center to smooth surface), round Earth model or oblate spheroid at the nadir of the aircraft. | | | | |

Annex A Page 11 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 140 of 343 |

ANSI/AIAA S-119


Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|--|--|--------------------------|---------------|-----------|-----------|
| | RALT | heightOfCmWrtTerrain_ft heightOfCmWrtTerrain_m or heightWrtTerrain_ft heightWrtTerrain_m | Height of the aircraft Cm above the terrain | NSC | | | |
| | HTERRAIN | heightOfTerrainWrtGround_ft heightOfTerrainWrtGround_m | Height of the terrain at the nadir of the aircraft Cm. It is the terrain height above the smooth surface of the Earth, regardless of whether a flat, round or oblate spheroid model is used. | | | | |

Table A.2 — Vehicle velocities and angular rates

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------|------------|---|--|--------------------------|---------------|-----------|-----------|
| V_{Txx} | VTxx | totalSpeedWrtXx_ft_s totalSpeedWrtXx_m_s | Total Velocity with respect to and observed from Xx where Xx is the coordinate system as defined in the body of this standard. | NSC | | | |
| V_K | VG | groundSpeed_ft_s groundSpeed_m_s | Vehicle speed along the ground . | NSC | | | |
| M_N | XMACH | mach | Mach number of the aircraft | NSC | | | |
| \dot{h}_{xx} | ALTDxx | xxAltitudeRate_ft_s xxAltitudeRate_m_s default coordinate system is locally level and -Z axis | Altitude time rate of change in xx coordinate system. | DN | | | |

Annex A Page 12 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 141 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--|------------|---|---|--------------------------|---------------|-----------|-----------|
| | XLOND | xxLongitudeRate_rad_s xxLongitudeRate_deg_s Default is Ge coordinate system | Longitude Rate Of Change in xx coordinate system. | WEST | | | |
| | XLATD | xxLatitudeRate_rad_s xxLatitudeRate_deg_s Default is Ge coordinate system | Geodetic Latitude Rate Of Change in xx coordinate system. | NORTH | | | |
| General Definition-Translational Velocities xxVelocityOfYyyWrtZzzObsFrWww_ft_s [3] xxVelocityOfYyyWrtZzzObsFrWww_m_s [3] | | | <p>General Definition for Translational Motion: Refer to section 6 of this standard for complete guidance on the naming of variables.</p> <p>General expression for vector of velocities presented (or measured) in the xx coordinate system. Yyy indicates the reference point on the vehicle and the OfYyy may be omitted if it is the Cm. Zzz represents the coordinate system that the vehicle is moving with respect to and WrtZzz may be omitted if it is the xx coordinate system. ObsFrWww represents the coordinate system from which the vehicle motion is observed. The ObsFrWww may be omitted if it is the Zzz coordinate system (see section 6.3.3 for more detail)</p> <p>Therefore eiVelocity_ft_s_X is the velocity of the vehicle Cm along the X axis of the ei coordinate system, measured with respect to the ei coordinate system and observed from the ei coordinate system and is the default expression for eiVelocityOfCmWrtEiObsFrEi_ft_s_X.</p> | | | | |
| General Definition-Angular Velocities xxAngularRateOfYyyWrtZzz_rad_s [3] xxAngularRateOfYyyWrtZzz_deg_s [3] | | | <p>General Definition for Rotational Motion: Refer to section 6 of this standard for complete guidance on the naming of variables.</p> <p>General expression for angular velocities presented in the xx coordinate system. Yyy indicates the reference coordinate system on the vehicle and the OfYyy may be omitted if it is the body coordinate system. Zzz represents the coordinate system that the vehicle is moving with respect to and from which the vehicle motion is observed. The WrtZzz may be omitted if it is the locally level (Ll) coordinate system. (see section 6.3.3 for more detail)</p> <p>Therefore eiAngularRate_rad_s_Roll is the angular rate of the body axis of the vehicle with respect to the locally level coordinate system and presented (or measured) in the Earth centered inertial (ei) coordinate system and is the default expression for eiAngularRateOfBodyWrtLl_rad_s_Roll</p> | | | | |

Annex A Page 13 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 142 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------|------------|--|--|--------------------------|---------------|-----------|-----------|
| Q | OM | bodyAngularRate_rad_s[3] bodyAngularRate_deg_s[3] | Vector of body coordinate angular rates of the ownship body coordinate system with respect to the locally level (LI) coordinate system. Comprised of the three components as defined below. Angular motion is always with respect to the LI coordinate system unless otherwise specified. | | | | |
| p | P | bodyAngularRate_rad_s_Roll bodyAngularRate_deg_s_Roll | Vehicle roll velocity, body coordinate system | RWD | | | |
| q | Q | bodyAngularRate_rad_s_Pitch bodyAngularRate_deg_s_Pitch | Vehicle pitch velocity, body coordinate system | ANU | | | |
| r | R | bodyAngularRate_rad_s_Yaw bodyAngularRate_deg_s_Yaw | Vehicle yaw velocity, body coordinate system | ANR | | | |
| Ω_B | OMB | bodyAngularRateWrtEi_rad_s[3] bodyAngularRateWrtEi_deg_s[3] | Vector of body coordinate angular rates with respect to the Earth centered inertial (Ei) coordinate system. Comprised of the three components as defined below. | | | | |
| p_B | PB | bodyAngularRateWrtEi_rad_s_Roll bodyAngularRateWrtEi_deg_s_Roll | Vehicle roll velocity, body coordinate system | RWD | | | |
| q_B | QB | bodyAngularRateWrtEi_rad_s_Pitch bodyAngularRateWrtEi_deg_s_Pitch | Vehicle pitch velocity, body coordinate system | ANU | | | |
| r_B | RB | bodyAngularRateWrtEi_rad_s_Yaw bodyAngularRateWrtEi_deg_s_Yaw | Vehicle yaw velocity, body coordinate system | ANR | | | |
| p_{rf} | PS | saAngularRateOfBodyWrtEi_rad_s_Roll saAngularRateOfBodyWrtEi_deg_s_Roll | Body coordinate system Roll rate about the X axis in the sa coordinate system, also know as stability axis roll rate. | RWD | | | |
| r_{rf} | RS | saAngularRateOfBodyWrtEi_rad_s_yaw saAngularRateOfBodyWrtEi_deg_s_yaw | Body coordinate system Yaw rate about the Z axis in the sa coordinate system, also known as the Stability Axis yaw rate | ANR | | | |

Annex A Page 14 of 54


| | | | | |
|---|---|--|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | | Document #: NESC-RP-09-00598 | Version: 1.0 |
| | Title: Flight Simulation Model Exchange | | | Page #: 143 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------------------|------------|--|---|--------------------------|---------------|-----------|-----------|
| $\dot{\underline{\epsilon}}$ | EULD | eulerAngleRate_deg_s[3] eulerAngleRate_rad_s[3] | Array of the roll, pitch, and yaw Euler angle rates defined below. LL (locally level) coordinate system | | | | |
| $\dot{\phi}$ | PHID | eulerAngleRate_rad_s_Roll | Euler roll rate, LL coordinate system | RWD | | | |
| $\dot{\theta}$ | THETD | eulerAngleRate_rad_s_Pitch | Euler pitch rate, LL coordinate system | ANU | | | |
| $\dot{\psi}$ | PSID | eulerAngleRate_rad_s_Yaw | Euler yaw rate, LL coordinate system | ANR | | | |
| \underline{V} | VEL [3] | bodyVelocityWrtAir_ft_s[3] bodyVelocityWrtAir_m_s[3] can also be expressed as: bodyVelocityOfCmWrtAir_ft_s[3] | Vector of body coordinate velocities of the Cm with respect to the instantaneous wind comprised of the three components as defined below. This is the conventional body coordinate system airspeed vector. | | | | |
| u | U | bodyVelocityWrtAir_ft_s_X bodyVelocityWrtAir_m_s_X | X-velocity Body coordinate system. | FWD | | | |
| v | V | bodyVelocityWrtAir_ft_s_Y bodyVelocityWrtAir_m_s_Y | Y-velocity Body coordinate system | RT | | | |
| w | W | bodyVelocityWrtAir_ft_s_Z bodyVelocityWrtAir_m_s_Z | Z-velocity Body coordinate system | DN | | | |
| \underline{V}_B | VELB[3] | bodyVelocityWrtEi_ft_s[3] bodyVelocityWrtEi_m_s[3] can also be expressed as: bodyVelocityOfCmWrtEi_ft_s[3] | Vector of body coordinate inertial velocities of the Cm comprised of the three components as defined below. | | | | |

Annex A Page 15 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 144 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------------|------------|--|---|--------------------------|---------------|-----------|-----------|
| u_B | UB | bodyVelocityWrtEi_ft_s_X bodyVelocityWrtEi_m_s_X | X-velocity Body coordinate system. | FWD | | | |
| v_B | VB | bodyVelocityWrtEi_ft_s_Y bodyVelocityWrtEi_m_s_Y | Y-velocity Body coordinate system | RT | | | |
| w_B | WB | bodyVelocityWrtEi_ft_s_Z bodyVelocityWrtEi_m_s_Z | Z-velocity Body coordinate system | DN | | | |
| \underline{V}_G | VELE[3] | bodyVelocityWrtGe_ft_s[3] bodyVelocityWrtGe_m_s[3] can also be expressed as: bodyVelocityOfCmWrtGe_ft_s[3] | Vector of body coordinate Cm velocities with respect to the geocentric Earth (Ge) coordinate system. Comprised of the three components as defined below. | | | | |
| u_E | UE | bodyVelocityWrtGe_ft_s_X bodyVelocityWrtGe_m_s_X | X-velocity Body coordinate system. | FWD | | | |
| v_E | VE | bodyVelocityWrtGe_ft_s_Y bodyVelocityWrtGe_m_s_Y | Y-velocity Body coordinate system | RT | | | |
| w_E | WE | bodyVelocityWrtGe_ft_s_Z bodyVelocityWrtGe_m_s_Z | Z-velocity Body coordinate system | DN | | | |
| \underline{V}_{FE} | VELFE | feVelocity_ft_s[3] feVelocity_m_s[3] | Vector of Flat Earth (FE) coordinate translational velocities of the Cm comprised of the three components as defined below. | | | | |
| V_N | VNFE | feVelocity_ft_s_X feVelocity_m_s_X | Northward Velocity Over Flat Earth (FE) coordinate system [flat, non-rotating Earth] | NORTH | | | |

Annex A Page 16 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 145 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-------------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| V_E | VEFE | feVelocity_ft_s_Y feVelocity_m_s_Y | Eastward Velocity Over Flat Earth (FE) coordinate system [flat, non-rotating Earth] | EAST | | | |
| V_D | VD FE | feVelocity_ft_s_Z feVelocity_m_s_Z | Downward Velocity Toward Earth Ctr., (FE) coordinate system [flat, non-rotating Earth] | DN | | | |
| \underline{V}_E | | geVelocity_ft_s [3] geVelocity_m_s [3] | Vector of Geocentric Earth (Ge) coordinate translational velocities of the Cm comprised of the three components as defined below. | | | | |
| V_{x_E} | VXGE | geVelocity_ft_s_X geVelocity_m_s_X | X axis velocity over the Earth in the geocentric Earth (GE) coordinate system in ft/sec | +X | | | |
| V_{y_E} | VYGE | geVelocity_ft_s_Y geVelocity_m_s_Y | Y axis velocity over the Earth in the geocentric Earth (GE) coordinate system in ft/sec | +Y | | | |
| V_{z_E} | VZGE | geVelocity_ft_s_Z geVelocity_m_s_Z | Y axis velocity over the Earth in the geocentric Earth (GE) coordinate system in ft/sec | +Z | | | |
| OTHER EXAMPLES | | | | | | | |
| $V_{x_{ge}}$ | VXGE | geVelocity_km_s_X | X axis velocity of the vehicle Cm is the geocentric (ge) coordinate system in kilometers/sec | +X | | | |
| | | runway22Velocity_ft_s_Z | Z axis velocity of the Cm in the user defined "runway22" coordinate system in ft/s | DN | | | |

Annex A Page 17 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 146 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

Table A.3 — Vehicle linear and angular accelerations

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| | | General Definition-Translational Accelerations $xxAccelOfYyyWrtZzzObsFrWww_ft_s2_ [3]$ $xxAccelOfYyyWrtZzzObsFrWww_m_s2_ [3]$ | <p>General Definition for Translational Motion: Refer to section 6 of this standard for complete guidance on the naming of variables.</p> <p>General expression for vector of accelerations presented (or measured) in the xx coordinate system. Yyy indicates the reference point on the vehicle and the $OfYyy$ may be omitted if it is the Cm. Zzz represents the coordinate system that the vehicle is moving with respect to and $WrtZzz$ may be omitted if it is the xx coordinate system. $ObsFrWww$ represents the coordinate system from which the vehicle motion is observed. The $ObsFrWww$ may be omitted if it is the Zzz coordinate system (see section 6.3.3 for more detail)</p> <p>Therefore $eiVelocity_ft_s2_X$ is the acceleration of the vehicle Cm along the X axis of the ei coordinate system, measured with respect to the ei coordinate system and observed from the ei coordinate system and is the default expression for $eiVelocityOfCmWrtEiObsFrEi_ft_s2_X$.</p> | | | | |
| | | General Definition-Angular Accelerations $xxAngularAccelOfYyyWrtZzz_rad_s2_ [3]$ $xxAngularAccelOfYyyWrtZzz_deg_s2_ [3]$ | <p>General Definition for Rotational Motion: Refer to section 6 of this standard for complete guidance on the naming of variables.</p> <p>General expression for angular accelerations presented in the xxx coordinate system. Yyy indicates the reference coordinate system on the vehicle and the $OfYyy$ may be omitted if it is the body coordinate system. Zzz represents the coordinate system that the vehicle is moving with respect to and from which the vehicle motion is observed. The $WrtZzz$ may be omitted if it is the locally level (Ll) coordinate system. (see section 6.3.3 for more detail)</p> <p>Therefore $eiAngularAccel_rad_s2_Roll$ is the angular acceleration of the body axis of the vehicle with respect to the locally level coordinate system and presented (or measured) in the Earth centered inertial (ei) coordinate system and is the default expression for $eiAngularAccelOfBodyWrtLl_rad_s2_Roll$</p> | | | | |
| $\dot{\theta}$ | OMBD | $bodyAngularAccel_rad_s2_ [3]$ $bodyAngularAccel_deg_s2_ [3]$ | Vector of body coordinate angular accelerations of the ownship body axis coordinate system with respect to the Locally level (Ll) coordinate system (Note: $WrtLl$ is the default and is therefore omitted), comprised of the three body axis components as defined below. | | | | |
| \dot{p} | PBD | $bodyAngularAccel_rad_s2_Roll$ $bodyAngularAccel_deg_s2_Roll$ | Aircraft Roll Acceleration, Body coordinate system | RWD | | | |


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 147 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------|------------|--|--|--------------------------|---------------|-----------|-----------|
| \dot{q} | QBD | bodyAngularAccel_rad_s2_Pitch bodyAngularAccel_deg_s2_Pitch | Aircraft Pitch Acceleration, Body coordinate system | ANU | | | |
| \dot{r} | RBD | bodyAngularAccel_rad_s2_Yaw bodyAngularAccel_deg_s2_Yaw | Aircraft Yaw Acceleration, Body coordinate system | ANR | | | |
| $\dot{\omega}_B$ | OMBDE | bodyAngularAccelWrtEi_rad_s2[3] bodyAngularAccelWrtEi_deg_s2[3] | Vector of body coordinate angular accelerations with respect to the Earth-centered inertial coordinate system, comprised of the three body axis components as defined below. | | | | |
| \dot{p}_B | PBDE | bodyAngularAccelWrtEi_rad_s2_Roll bodyAngularAccelWrtEi_deg_s2_Roll | Aircraft Roll Acceleration, Body coordinate system | RWD | | | |
| \dot{q}_B | QBDE | bodyAngularAccelWrtEi_rad_s2_Pitch bodyAngularAccelWrtEi_deg_s2_Pitch | Aircraft Pitch Acceleration, Body coordinate system | ANU | | | |
| \dot{r}_B | RBDE | bodyAngularAccelWrtEi_rad_s2_Yaw bodyAngularAccelWrtEi_deg_s2_Yaw | Aircraft Yaw Acceleration, Body coordinate system | ANR | | | |
| \dot{V}_B | | bodyAccelWrtEi_ft_s2[3] bodyAccelWrtEi_m_s2[3] | Vector of accelerations of the Cm of the aircraft with respect to and observed from the Ei coordinate system (Earth-centered inertial) in the body coordinate system. This variable includes the gravitation vector. Comprised of the three components as defined below. | | | | |
| \dot{u}_B | UBD | bodyAccelWrtEi_ft_s2_X bodyAccelWrtEi_m_s2_X | Longitudinal acceleration (along the X-body coordinate) | FWD | | | |
| \dot{v}_B | VBD | bodyAccelWrtEi_ft_s2_Y bodyAccelWrtEi_m_s2_Y | Right Sideward Acceleration, Body coordinate | RT | | | |
| \dot{w}_B | WBD | bodyAccelWrtEi_ft_s2_Z bodyAccelWrtEi_m_s2_Z | Downward Acceleration, Body coordinate | DNDN | | | |

Annex A Page 19 of 54


| | | | |
|---|---|--|------------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 148 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-------------------------|------------|---|--|--------------------------|---------------|-----------|-----------|
| $\underline{\dot{V}}$ | | bodyAccelWrtAir_ft_s2[3] bodyAccelWrtAir_m_s2[3] | Vector of body coordinate accelerations of the Cm with respect to the mean air mass and comprised of the three components as defined below. This variable includes the gravitation vector. Comprised of the three components as defined below. | | | | |
| $\underline{\dot{u}}$ | | bodyAccelWrtAir_ft_s2_X bodyAccelWrtAir_m_s2_X | Longitudinal acceleration (along the X-body coordinate) | FWD | | | |
| $\underline{\dot{v}}$ | | bodyAccelWrtAir_ft_s2_Y bodyAccelWrtAir_m_s2_Y | Right Sideward Acceleration, along the Y Body coordinate | RT | | | |
| $\underline{\dot{w}}$ | | bodyAccelWrtAir_ft_s2_Z bodyAccelWrtAir_m_s2_Z | Downward Acceleration, along the Z Body coordinate | DNDN | | | |
| $\underline{\dot{V}}_E$ | | bodyAccelWrtGe_ft_s2[3] bodyAccelWrtGe_m_s2[3] | Vector of body coordinate Cm velocities with respect to the geocentric Earth (Ge) coordinate system. Comprised of the three components as defined below. This variable includes the gravitation vector. Comprised of the three components as defined below. | | | | |
| $\underline{\dot{u}}_E$ | | bodyAccelWrtGe_ft_s2_X bodyAccelWrtGe_m_s2_X | Longitudinal acceleration (along the X-body coordinate) | FWD | | | |
| $\underline{\dot{v}}_E$ | | bodyAccelWrtGe_ft_s2_Y bodyAccelWrtGe_m_s2_Y | Right Sideward Acceleration, along the Y Body coordinate | RT | | | |
| $\underline{\dot{w}}_E$ | | bodyAccelWrtGe_ft_s2_Z bodyAccelWrtGe_m_s2_Z | Downward Acceleration, along the Z Body coordinate | DN | | | |
| | | totalAccelWrtEi_ft_s2 | Magnitude of the inertial acceleration vector | NSC | | | |

Annex A Page 20 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 149 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|---|--------------------------|---------------|-----------|-----------|
| | VTDxx | totalVelocityRateWrtXx_ft_s2 totalVelocityRateWrtXx_m_s2 | Rate of change of speed with respect to and observed from Xx, where xx is the coordinate system as defined in the body of this standard. Total velocity (speed) rate of change is not the same as total acceleration (magnitude of the acceleration vector). For example, a velocity vector that only undergoes a direction change shows zero change in speed (magnitude) but still shows a positive total acceleration due to its direction change. | INC | | | |
| | | xxAccel_ft_s2 [3] xxAccel_m_s2 [3] | General form for the vector of aircraft Cm translational acceleration with respect to and observed from the specified (xx) coordinate system comprised of the three components as defined below. | | | | |
| | | xxAccel_ft_s2_X xxAccel_m_s2_X | X-axis acceleration in xx coordinate system | +X | | | |
| | | xxAccel_ft_s2_Y xxAccel_m_s2_Y | Y-axis acceleration in xx coordinate system | +Y | | | |
| | | xxAccel_ft_s2_Z xxAccel_m_s2_Z | Z-axis acceleration in xx coordinate system | +Z | | | |
| | | bodyAccelOfImuWrtEi_ft_s2[3] bodyAccelOfImuWrtEi_m_s2[3] | Vector of true inertial accelerations at the inertial measurement unit (Imu) including the effects of the gravitation vector. This variable assumes a perfect Imu. Comprised of the three body coordinate system components as defined below. | | | | |

Annex A Page 21 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 150 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|---|--------------------------|---------------|-----------|-----------|
| | AX | bodyAccelOfImuWrtEi_ft_s2_X bodyAccelOfImuWrtEi_m_s2_X | X Acceleration Of aircraft Cm (body coordinate) Includes the gravitation vector. | FWD | | | |
| | AY | bodyAccelOfImuWrtEi_ft_s2_Y bodyAccelOfImuWrtEi_m_s2_Y | Y Acceleration Of aircraft Cm (body coordinate) Includes the gravitation vector. | RT | | | |
| | AZ | bodyAccelOfImuWrtEi_ft_s2_Z bodyAccelOfImuWrtEi_m_s2_Z | Z Acceleration Of aircraft Cm (body coordinate) Includes the gravitation vector. | DN | | | |
| | | bodySensedAccelOfImuWrtEi_ft_s2 [3] bodySensedAccelOfImuWrtEi_m_s2 [3] | Vector of sensed inertial accelerations at the inertial measurement unit (Imu) including the effects of the gravitation vector. This variable includes any sensor scale, bias and noise.. Comprised of the three body coordinate system components as defined below. | | | | |
| | | bodySensedAccelOfImuWrtEi_ft_s2_X bodySensedAccelOfImuWrtEi_m_s2_X | X Acceleration Of aircraft Cm (body coordinate) Includes the gravitation vector. | FWD | | | |
| | | bodySensedAccelOfImuWrtEi_ft_s2_Y bodySensedAccelOfImuWrtEi_m_s2_Y | Y Acceleration Of aircraft Cm (body coordinate) Includes the gravitation vector. | RT | | | |
| | | bodySensedAccelOfImuWrtEi_ft_s2_Z bodySensedAccelOfImuWrtEi_m_s2_Z | Z Acceleration Of aircraft Cm (body coordinate) Includes the gravitation vector. | DN | | | |
| | | bodyAccelOfPilotWrtEi_ft_s2 [3] bodyAccelOfPilotWrtEi_m_s2 [3] | Vector of inertial accelerations at the pilot reference point, in the body coordinate system, comprised of the three components as defined below. | | | | |

Annex A Page 22 of 54


| | | | | |
|---|---|--|-------------------------|------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | | Document #: | Version: |
| | | | NESC-RP-09-00598 | 1.0 |
| Title: | | | Page #: | |
| Flight Simulation Model Exchange | | | 151 of 343 | |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|--|--------------------------|---------------|-----------|-----------|
| | AXP | bodyAccelOfPilotWrtEi_ft_s2_X bodyAccelOfPilotWrtEi_m_s2_X | X Acceleration Of Pilot reference point (body coordinate) | FWD | | | |
| | AYP | bodyAccelOfPilotWrtEift_s2_Y bodyAccelOfPilotWrtEi_m_s2_Y | Y Acceleration Of Pilot reference point (body coordinate) | RT | | | |
| | AZP | bodyAccelOfPilotWrtEi_ft_s2_Z bodyAccelOfPilotWrtEi_m_s2_Z | Z Acceleration Of Pilot reference point (body coordinate) | DN | | | |
| | GVBODY [3] | bodyLocalGravitation_ft_s2 [3] bodyLocalGravitation_m_s2 [3] | Local gravitation vector in the body coordinate system. | | | | |
| | GVBODYX | bodyLocalGravitation_ft_s2_X bodyLocalGravitation_m_s2_X | X axis component | FWD | | | |
| | GVBODYY | bodyLocalGravitation_ft_s2_Y bodyLocalGravitation_m_s2_Y | Y axis component | RT | | | |
| | GVBODYZ | bodyLocalGravitation_ft_s2_Z bodyLocalGravitation_m_s2_Z | Z axis component | DN | | | |
| | GVGE [3] | geLocalGravitation_ft_s2 [3] geLocalGravitation_m_s2 [3] | Local gravitation vector in the ge (geocentric Earth) coordinate system. | | | | |
| | GVGEX | geLocalGravitation_ft_s2_X geLocalGravitation_m_s2_X | X axis component | FWD | | | |
| | GVGEY | geLocalGravitation_ft_s2_Y geLocalGravitation_m_s2_Y | Y axis component | RT | | | |

Annex A Page 23 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 152 of 343 |


ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|---|--------------------------|---------------|-----------|-----------|
| | GVEZ | geLocalGravitation_ft_s2_Z geLocalGravitation_ft_s2_Z | Z axis component | DN | | | |
| | GVEI[3] | eiLocalGravitation_ft_s2 [3] eiLocalGravitation_m_s2 [3] | Local gravitation vector in the ei (Earth centered inertial) coordinate system. | | | | |
| | GVEIX | eiLocalGravitation_ft_s2_X eiLocalGravitation_ft_s2_X | X axis component | FWD | | | |
| | GVEIY | eiLocalGravitation_ft_s2_Y eiLocalGravitation_ft_s2_Y | Y axis component | RT | | | |
| | GVEIZ | eiLocalGravitation_ft_s2_Z eiLocalGravitation_ft_s2_Z | Z axis component | DN | | | |
| | G | localGravity_ft_s2 localGravity_m_s2 | Acceleration Due To Gravity (at the vehicle altitude), in the LI coordinate system. | DN | | | |

Table A.4 — Vehicle air data

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------|------------|--|---------------------------------------|--------------------------|---------------|------------------|------------------|
| α | ALFA | angleOfAttack_deg angleOfAttack_rad | Angle Of Attack, Body coordinate | ANU | | $-\pi$, -180 | $+\pi$, +180 |
| β | BETA | angleOfSideslip_deg angleOfSideslip_rad | Sideslip Angle, Body coordinate | ANL | | $-\pi$, -180 | $+\pi$, +180 |
| $\dot{\alpha}$ | ALFD | angleOfAttackRate_rad_s | Angle Of Attack Rate, Body coordinate | ANU | | | |


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 153 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|---------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| $\dot{\beta}$ | BETD | angleOfSideslipRate_rad_s | Sideslip Angle Rate | ANL | | | |
| $\sin \alpha$ | SALPH | sineAngleOfAttack | Sine Of Angle Of Attack | ANU | | -1.0 | 1.0 |
| $\cos \alpha$ | CALPH | cosineAngleOfAttack | Cosine Of Angle Of Attack | ANU | | -1.0 | 1.0 |
| $\sin \beta$ | SBETA | sineAngleOfSideslip | Sine Of Sideslip Angle | ANL | | -1.0 | 1.0 |
| $\cos \beta$ | CBETA | cosineAngleOfSideslip | Cosine Of Sideslip Angle | ANL | | -1.0 | 1.0 |
| V_{CAL} | VCAL | calibratedAirspeed_nmi_h | Calibrated Air Speed, knots | FWD | | | |
| V_{EQ} | VEQ | equivalentAirspeed_nmi_h | Equivalent Air Speed | FWD | | | |
| V_{IND} | VCAL | indicatedAirspeed_nmi_h | Calibrated Air Speed, | FWD | | | |
| V | VRW | trueAirspeed_ft_s trueAirspeed_m_s trueAirspeed_nmi_h | Vehicle Velocity relative to the local wind (true airspeed) | FWD | | | |
| \bar{q} | QBAR | dynamicPressure_lbf_ft2 dynamicPressure_N_m2 | Dynamic Pressure | NSC | | | |
| \bar{q}_c | QBARC | impactPressure_lbf_ft2 impactPressure_N_m2 | Impact Pressure | NSC | | | |
| ρ | RHO | airDensity_lbm_ft3 airDensity_kg_m3 | Air Density, At Altitude of the aircraft | NSC | | | |
| | DENALT | densityAltitude_ft densityAltitude_m | Density altitude | | | | |

Annex A Page 25 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 154 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-------------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| a | SOUND | speedOfSound_ft_s | Velocity Of Sound At Altitude of the aircraft | NSC | | | |
| | | speedOfSound_m_s | | | | | |
| T _{TOTR} | TR | totalTempRatio totalTempRatio | Total Temperature Ratio | NSC | | | |
| P _{TOTR} | PR | totalPressureRatio totalPressureRatio | Total Pressure Ratio | NSC | | | |
| T _{AMB} | TAMB | ambientTemperature_dgC ambientTemperature_dgK | Ambient Temperature at altitude | NSC | | | |
| P _{AMB} | PAMB | ambientPressure_lbf_ft2 ambientPressure_N_m2 | Ambient Pressure at altitude | NSC | | | |
| P _{AMBR} | PAMBR | ambientPressureRatio | Ratio Of ambient pressure at altitude to sea level ambient pressure | NSC | | | |
| T _{AMBR} | TAMBR | ambientTemperatureRatio | Ratio Of ambient temperature at altitude to sea level ambient temp. | NSC | | | |
| t _T | TTOT | totalTemp_dgC totalTemp_dgK | Total Temperature at altitude | NSC | | | |
| p _T | PTOT | totalPressure_lbf_ft2 totalPressure_N_m2 | Total Pressure at altitude | NSC | | | |
| | TAMB | ambientTemperatureAtAlt_dgK ambientTemperatureAtAlt_dgR ambientTemperatureAtAlt_dgC | Ambient temperature, at the altitude of the Cm | | | | |

Annex A Page 26 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 155 of 343 |

ANSI/AIAA S-119


Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|---|--------------------------|---------------|-----------|-----------|
| | TTOT | totalTemperatureAtAlt_dgK totalTemperatureAtAlt_dgR totalTemperatureAtAlt_dgC | Total temperature at the altitude of the Cm | | | | |
| | ALT_SET | instrumentAltimeterSetting_inchMercury | Cockpit Altimeter setting (Kohlsman window) | 29.92 is standard day | | | |
| | P_ALT | pressureAltitude_ft pressureAltitude_m | Pressure altitude at the Cm | | | | |
| | RHO_SL | seaLevelAirDensity_lbm_ft3 | Air density at sea level | | | | |
| | TAMB_SL | seaLevelAmbientTemp_dgK seaLevelAmbientTemp_dgC | Ambient temperature at mean sea level | | | | |
| | PAMB_SL | seaLevelAmbientPressure_lbf_ft2 seaLevelAmbientPressure_N_m2 | Ambient pressure at sea level | | | | |

Table A.5 — Atmospheric disturbances and turbulence

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|----------------|---|--|--------------------------|---------------|-----------|-----------|
| | WIND_SPEED | meanAirMassSpeed_ft_s meanAirMassSpeed_m_s | Total velocity of mean wind | | | | |
| | WIND_DIRECTION | meanAirMassDirection_deg | Mean wind direction | Wind blowing FROM North | | | |
| V_w | VTWS | totalWindSpeed_ft_s totalWindSpeed_m_s | Total Wind Speed (mean wind plus turbulence) | NSC | | | |

Annex A Page 27 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 156 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| \underline{V}_{WT_i} | | $llTurbulenceVelocityWrtGe_ft_s[3]$ $llTurbulenceVelocityWrtGe_m_s[3]$ | Vector of locally level coordinate wind turbulence velocities with respect to the geocentric earth (Ge) fixed coordinate system. Comprised of the three components as defined below. Note: This vector is designed to be transformed from the GRAM 07 small wind perturbation velocities. GRAM 07 outputs the wind perturbation vector. $usmall$ (+ East) $vsmall$ (+ North) $wsmall$ (+ UP) Therefore: $llturbulenceVelocityWrtGe_m_s_X = vsmall$ $llturbulenceVelocityWrtGe_m_s_Y = usmall$ $llturbulenceVelocityWrtGe_m_s_Z = -wsmall$ | | | | |
| N_{WT_i} | NSMALL | $llTurbulenceVelocityWrtGe_ft_s_X$ $llTurbulenceVelocityWrtGe_m_s_X$ | X-velocity Turb. Component | to the North | | | |
| E_{WT_i} | ESMALL | $llTurbulenceVelocityWrtGe_ft_s_Y$ $llTurbulenceVelocityWrtGe_m_s_Y$ | Y-velocity Turb. Component | to the East | | | |
| D_{WT_i} | DSMALL | $llTurbulenceVelocityWrtGe_ft_s_Z$ $llTurbulenceVelocityWrtGe_m_s_Z$ | Z-velocity Turb. Component | to downward | | | |
| \underline{V}_{Turb} | VELBWT | $bodyTurbulenceVelocityWrtGe_ft_s[3]$ $bodyTurbulenceVelocityWrtGe_m_s[3]$ | Vector of body coordinate translational turbulence velocities comprised of the three components as defined below. | | | | |
| U_{Turb} | UBTURB | $bodyTurbulenceVelocityWrtGe_ft_s_X$ $bodyTurbulenceVelocityWrtGe_m_s_X$ | X-velocity Turb. Component, Body coordinate | FWD (tailwind) | | | |
| V_{Turb} | VBTURB | $bodyTurbulenceVelocityWrtGe_ft_s_Y$ $bodyTurbulenceVelocityWrtGe_m_s_Y$ | Y-velocity Turb. Component, Body coordinate | RT | | | |

Annex A Page 28 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 157 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------|------------|---|--|--------------------------|---------------|-----------|-----------|
| W_{Turb} | WBTURB | bodyTurbulenceVelocityWrtGe_ft_s_Z bodyTurbulenceVelocityWrtGe_m_s_Z | Z-velocity Turb. Component, Body coordinate | DN | | | |
| V_{WM} | VELMW | llVelocityOfMeanAirMassWrtGe_ft_s[3] llVelocityOfMeanAirMassWrtGe_m_s[3] | Vector of locally level coordinate mean wind translational velocities comprised of the three components as defined below Note: This vector is designed to be transformed from the GRAM 07 wind model velocities. GRAM 07 outputs the mean wind velocity vector. umean (+ East) vmean (+ North) wmean (+ UP) Therefore: llVelocityOfMeanAirMassWrtGe_m_s_X = vmean llVelocityOfMeanAirMassWrtGe_m_s_Y = umean llVelocityOfMeanAirMassWrtGe_m_s_Z = -wmean | | | | |
| N_{M} | NMEAN | llVelocityOfMeanAirMassWrtGe_ft_s_X llVelocityOfMeanAirMassWrtGe_m_s_X | X-velocity Component, locally level coordinate system | to the North | | | |
| E_{M} | EMEAN | llVelocityOfMeanAirMassWrtGe_ft_s_Y llVelocityOfMeanAirMassWrtGe_m_s_Y | Y-velocity Component, locally level coordinate system | to the East | | | |
| D_{M} | DMEAN | llVelocityOfMeanAirMassWrtGe_ft_s_Z llVelocityOfMeanAirMassWrtGe_m_s_Z | Z-velocity Component, locally level coordinate system | to downward | | | |

Annex A Page 29 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 158 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| \underline{V}_{WM_B} | VELMWB | bodyVelocityOfMeanAirMassWrtGe_ft_s[3] bodyVelocityOfMeanAirMassWrtGe_m_s[3] | Vector of body coordinate system mean wind translational wind velocities comprised of the three components as defined below. Note: This vector is designed to be the GRAM 07 wind model mean velocities transformed into the body coordinate system. | | | | |
| u_{WM_B} | UMEANB | bodyVelocityOfMeanAirMassWrtGe_ft_s_X bodyVelocityOfMeanAirMassWrtGe_m_s_X | X-velocity Component, body coordinate system | FWD (tailwind) | | | |
| v_{WM_B} | VMEANB | bodyVelocityOfMeanAirMassWrtGe_ft_s_Y bodyVelocityOfMeanAirMassWrtGe_m_s_Y | Y-velocity Component, body coordinate system | To the RT | | | |
| w_{WM_B} | WMEANB | bodyVelocityOfMeanAirMassWrtGe_ft_s_Z bodyVelocityOfMeanAirMassWrtGe_m_s_Z | Z-velocity Component, body coordinate system | DN | | | |
| \underline{V}_{TW} | VTW | bodyWindVelocityWrtGe_ft_s[3] bodyWindVelocityWrtGe_m_s[3] | Vector of the body coordinate system of net wind velocities impinging on the aircraft at the Cm. This would include mean air mass motion and any disturbances such as turbulence and shear. Comprised of the three components as defined below. Note: Winds are always with respect to and observed from an Earth-fixed reference frame. This vector is with respect to the geocentric Earth (Ge)fixed coordinate system. | | | | |
| U_{TW} | UBTWX | bodyWindVelocityWrtGe_ft_s_X bodyWindVelocityWrtGe_m_s_X | Net wind velocity impinging on the vehicle in the X body axis. Net wnd is the mean air mass plus any turbulence, shears, or other wind disturbances. | FWD (tailwind) | | | |

Annex A Page 30 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 159 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------|------------|--|---|--|---------------|-----------|-----------|
| V_{TW} | VBTWY | bodyWindVelocityWrtGe_ft_s_Y bodyWindVelocityWrtGe_m_s_Y | Net wind velocity impinging on the vehicle in the Y body axis Net wind is the mean air mass plus any turbulence, shears, or other wind disturbances. | RT | | | |
| W_{TW} | VBTWZ | bodyWindVelocityWrtGe_ft_s_Z bodyWindVelocityWrtGe_m_s_Z | Net wind velocity impinging on the vehicle in the Z body axis Net wind is the mean air mass plus any turbulence, shears, or other wind disturbances. | DN | | | |
| | | bodyAngularRateTurbulenceWrtLl_deg_s [3] bodyAngularRateTurbulenceWrtLl_rad_s [3] | Vector of angular turbulence velocities comprised of the three body coordinate system components as defined below. Note: Turbulence angular rate is always with respect to and observed from the locally level (LI) reference frame. | | | | |
| | PTURB | bodyAngularRateTurbulenceWrtLl_deg_s_Roll bodyAngularRateTurbulenceWrtLl_rad_s_Roll | Body coordinate roll turbulence | The turbulence would move the aircraft right wing down | | | |
| | QTURB | bodyAngularRateTurbulenceWrtLl_deg_s_Pitch bodyAngularRateTurbulenceWrtLl_rad_s_Pitch | Body coordinate pitch turbulence | The turbulence would move the aircraft nose up | | | |
| | RTURB | bodyAngularRateTurbulenceWrtLl_deg_s_Yaw bodyAngularRateTurbulenceWrtLl_rad_s_Yaw | Body coordinate yaw turbulence | The turbulence would move the aircraft nose right | | | |

Annex A Page 31 of 54

| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 160 of 343 |


ANSI/AIAA S-119

Annex A. Standard Variable Names

Table A.6 — Vehicle physical characteristics

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------|------------|---|--|--------------------------|---------------|-----------|-----------|
| I | | bodyMomentOfInertia_slugft2 [3,3] bodyMomentOfInertia_kgm2 [3,3] | Matrix of the total moments of inertia of the aircraft. This is with respect to the Cm and includes everything in or attached to the aircraft (stores, passengers, crew, fuel, etc.). It is comprised of the components below. $\begin{matrix} I_{xx} & -I_{xy} & -I_{zx} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{yz} & I_{zz} \end{matrix}$ | | | | |
| I_x | XIXX | bodyMomentOfInertia_slugft2_X bodyMomentOfInertia_kgm2_X | Vehicle Roll Moment Of Inertia about Cm, body coordinate system | NSC | | | |
| I_y | XIYY | bodyMomentOfInertia_slugft2_Y bodyMomentOfInertia_kgm2_Y | Vehicle Pitch Moment Of Inertia about Cm, body coordinate system | NSC | | | |
| I_z | XIZZ | bodyMomentOfInertia_slugft2_Z bodyMomentOfInertia_kgm2_Z | Vehicle Yaw Moment Of Inertia about Cm, body coordinate system | NSC | | | |
| I_{xz} | XIZX | bodyProductOfInertia_slugft2_ZX bodyProductOfInertia_kgm2_ZX | Vehicle ZX Cross Product Of Inertia about Cm, body coordinate system | NSC | | | |
| I_{xy} | XIXY | bodyProductOfInertia_slugft2_XY bodyProductOfInertia_kgm2_XY | Vehicle XYy Cross Product Of Inertia about Cm, body coordinate system | NSC | | | |
| I_{yz} | XIYZ | bodyProductOfInertia_slugft2_YZ bodyProductOfInertia_kgm2_YZ | Vehicle YZ Cross Product Of Inertia about Cm, body coordinate system | NSC | | | |

Annex A Page 32 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 161 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-----------------|------------|---|--|---|---------------|-----------|-----------|
| | MrcPos | vrsPositionOfMrc_ft[3] vrsPositionOfMrc_m[3] | Vector of the location of the moment reference center (Mrc) of the aircraft in the vehicle reference system (vrs). Comprised of the three components as defined below. This vector is used to define the fixed physical location of the moment reference center in the vehicle. Note that the vrs definition is specific to each vehicle. | | | | |
| | XMrc | vrsPositionOfMrc_ft vrsPositionOfMrc_m | X Mrc Position | | | | |
| | YMrc | vrsPositionOfMrc_ft vrsPositionOfMrc_m | Y Mrc Position | | | | |
| | ZMrc | vrsPositionOfMrc_ft vrsPositionOfMrc_m | Z Mrc position | | | | |
| Δ_{cg} | DCG | bodyPositionOfCmWrtMrc_ft [3] | Vector of the location of the Cm with respect to the moment reference center (Mrc) of the aircraft in the body coordinate system. Comprised of the three components as defined below. This vector is used to define the location of the Cm which moves Wrt to the fixed moment reference center in the vehicle. Note that vrsPositionOfMrc locates the Mrc in the vehicle. | | | | |
| ΔX_{cg} | DXCG | bodyPositionOfCmWrtMrc_ft_X bodyPositionOfCmWrtMrc_m_X | X Cm position | Cm forward of the Mrc | | | |
| ΔY_{cg} | DYCG | bodyPositionOfCmWrtMrc_ft_Y bodyPositionOfCmWrtMrc_m_Y | Y Cm position | Cm to the right (out the right wing) of the Mrc | | | |
| ΔZ_{cg} | DZCG | bodyPositionOfCmWrtMrc_ft_Z bodyPositionOfCmWrtMrc_m_Z | Z Cm position | Cm below the Mrc | | | |
| m | XMASS | totalMass_slug totalMass_kg | Total Mass Of Vehicle (including Fuel, crew, cargo, stores, passengers, etc.) | NSC | | | |

Annex A Page 33 of 54


| | | | |
|---|---|--|------------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 162 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------|------------|---|---|--------------------------|---------------|-----------|-----------|
| W | WEIGHT | grossWeight_lbf grossWeight_N | Aircraft Gross Weight (mass*gravity), including all fuel, occupants, stores, etc. | NSC | | | |
| S | AREA | referenceWingArea_ft2 referenceWingArea_m2 | Reference Wing Area | NSC | | | |
| b | SPAN | referenceWingSpan_ft referenceWingSpan_m | Reference Wing Span | NSC | | | |
| c | CHORD | referenceWingChord_ft referenceWingChord_m | Mean Aerodynamic Chord (reference wing chord) | NSC | | | |
| | | engineMomentOfInertia_slugft2[3,3] engineMomentOfInertia_kgm2[3,3] | Matrix of the moments of inertia of the Rotating engine, for an engine with the propeller, includes the propeller and drive train. This is w.r.t. the rotational axis of the engine. For multi-engine vehicles is for one engine. It is comprised of the components below. $\begin{matrix} I_{EXX} & -I_{EXY} & -I_{EZX} \\ -I_{EXY} & I_{EYY} & -I_{EYZ} \\ -I_{EZX} & -I_{EYZ} & I_{EZZ} \end{matrix}$ | | | | |
| I_{Ex} | IEXX | engineMomentOfInertia_slugft2_X engineMomentOfInertia_kgm2_X | Moment of inertia about the X-axis Of Rotating Eng, for an engine with the propeller, includes the propeller This is w.r.t. the rotational axis of the engine | | | | |

Annex A Page 34 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 163 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-----------|------------|---|--|--------------------------|---------------|-----------|-----------|
| I_{Ey} | IEYY | engineMomentOfInertia_slugft2_Y engineMomentOfInertia_kgm2_Y | Moment of inertia about the Y-axis Of Rotating Eng, for an engine with the propeller, includes the propeller This is w.r.t. the rotational axis of the engine | | | | |
| I_{Ez} | IEZZ | engineMomentOfInertia_slugft2_Z engineMomentOfInertia_kgm2_Z | Moment of inertia about the Z-axis Of Rotating Eng, for an engine with the propeller, includes the propeller This is w.r.t. the rotational axis of the engine | | | | |
| I_{Exz} | IEZX | engineProductOfInertia_slugft2_XZ engineProductOfInertia_kgm2_XZ | Product of inertia about the XZ-axis Of Rotating Eng, for an engine with the propeller, includes the propeller This is w.r.t. the rotational axis of the engine | | | | |
| I_{Exy} | IEXY | engineProductOfInertia_slugft2_XY engineProductOfInertia_kgm2_XY | Product of inertia about the XY-axis Of Rotating Eng, for an engine with the propeller, includes the propeller This is w.r.t. the rotational axis of the engine | | | | |

Annex A Page 35 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 164 of 343 |

ANSI/AIAA S-119


Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-----------|------------|---|---|---|---------------|-----------|-----------|
| I_{EYZ} | IEYZ | engineProductOfInertia_slugft2_YZ engineProductOfInertia_kgm2_YZ | Product of inertia about the YZ-axis Of Rotating Eng, for an engine with the propeller, includes the propeller This is w.r.t the rotational axis of the engine | | | | |
| | | fuelInTank_lbm[number of fuel tanks] fuelInTank_kg[number of fuel tanks] | Vector of fuel weight by tank. Each aircraft tank is normally numbered and the vector should be ordered according to fuel tank number. In the absence of tank numbering the convention of port to starboard, upper to lower, then front to rear should be used. | | | | |
| | | fuelTankCentroid_ft[number of fuel tanks,3] fuelTankCentroid_m[number of fuel tanks,3] | Matrix used to locate the centroids of the fuel tanks. Each aircraft tank is normally numbered and the matrix should be ordered according to fuel tank number. The second component is the x, y and z moment arms from the moment reference center to the tank centroid in the structural coordinate system. In the absence of tank numbering the convention of port to starboard, upper to lower, then front to rear should be used. | Tank centroid behind, right, and below the moment reference center. | | | |

Table A.7 — Vehicle control position

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|--------------------|-------------|--------------------------|---------------|-----------|-----------|
|--------|------------|--------------------|-------------|--------------------------|---------------|-----------|-----------|

Annex A Page 36 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 165 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|---|------------|--|---|---|---------------|-----------|-----------|
| Standard naming convention for crew control inputs "Pos" indicates a position input "Rate" indicates the derivative of the position input "Accel" indicates the derivative of the rate "Force" indicates the force input | | | Control positions for a vehicle are often uniquely defined for that vehicle, therefore the: Description Positive Sign Convention Initial Value Min Value Max Value definitions may all change based on the particular vehicle. The table below shall be used as default descriptions and values when they are not otherwise explicitly defined for the vehicle. | | | | |
| D_{η_m} | | pilotControlPos_deg_long pilotControlPos_rad_long | Longitudinal control position of the pilot. | AFT 0= vertical when vehicle body is level (pitch and roll attitude = 0) | | | |
| | | pilotControlRate_deg_s_long pilotControlRate_rad_s_long | Rate of the pilot Longitudinal control movement. | Moving aft | | | |
| | | pilotControlAccel_deg_s2_long pilotControlAccel_rad_s2_long | Acceleration of the pilot Longitudinal control movement. | Accelerating aft | | | |
| | | pilotControlForce_lbf_long pilotControlForce_N_long | Longitudinal control force of the pilot. | Aft force | | | |
| The convention and examples above apply to all pilot and copilot controls defined below | | | | | | | |

Annex A Page 37 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 166 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------|------------|--|---|--|---------------|-----------|-----------|
| D_{δ} | | pilotControlPos_deg_lat pilotControlPos_rad_lat | Lateral control position of the pilot. | LEFT 0= vertical when vehicle body is level (pitch and roll attitude = 0) | | | |
| D_{η} | | pilotControlPos_deg_avgPedal pilotControlPos_rad_avgPedal | Net Directional control position of the pilot. Normally, left pedal + right pedal. | Left Pedal in or counter clockwise twist of a sidestick | | | |
| | | pilotControlPos_deg_rtPedal pilotControlPos_rad_rtPedal | Right Directional control position of the pilot. | NEGATIVE for Pedal in 0= pedal full aft | | | 0.0 |
| | | pilotControlPos_deg_ltPedal pilotControlPos_rad_ltPedal | Left Directional control position of the pilot. | Pedal in. 0= pedal full aft | | 0.0 | |
| $D_{\delta z}$ | | pilotControlPos_deg_collective pilotControlPos_rad_collective | Pilot collective control position. | UP 0 = full down | | 0.0 | |
| | | pilotControlPos_deg_avgThrottle pilotControlPos_rad_avgThrottle | Average pilot throttle control position. | FWD 0= full aft w/o thrust reversing. Thrust reversing is negative | | | |
| | | pilotControlPos_deg_throttle [number of engines] pilotControlPos_rad_throttle [number of engines] | Individual pilot throttle control positions. Order is outboard port (left) to outboard starboard. | FWD 0= full aft w/o thrust reversing. Thrust reversing is negative | | | |

Annex A Page 38 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 167 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|--|--|--|---------------|-----------|-----------|
| | | copilotControlPos_deg_long copilotControlPos_rad_long | Longitudinal control position of the copilot. | AFT 0= vertical when vehicle body is level (pitch and roll attitude = 0) | | | |
| | | copilotControlPos_deg_lat copilotControlPos_rad_lat | Lateral control position of the copilot. | LEFT 0= vertical when vehicle body is level (pitch and roll attitude = 0) | | | |
| | | copilotControlPos_deg_avgPedal copilotControlPos_rad_avgPedal | Net Directional control position of the copilot. Normally, Left pedal + right pedal. | Left Pedal in or counter clockwise twist of a sidestick | | | |
| | | copilotControlPos_deg_rtPedal copilotControlPos_rad_rtPedal | Right Directional control position of the copilot. | NEGATIVE for Pedal in 0= pedal full aft | | | 0.0 |
| | | copilotControlPos_deg_ltPedal copilotControlPos_rad_ltPedal | Left Directional control position of the copilot. | Pedal in. 0= pedal full aft | | 0.0 | |
| | | copilotControlPos_deg_collective copilotControlPos_rad_collective | Copilot collective control position. | UP 0 = full down | | 0.0 | |
| | | copilotControlPos_deg_avgThrottle copilotControlPos_rad_avgThrottle | Average copilot throttle control position. | FWD 0= full aft w/o thrust reversing. Thrust reversing is negative | | | |

Annex A Page 39 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 168 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|--|---|---|---------------|-----------|-----------|
| | | copilotControlPos_deg_throttle [number of engines] copilotControlPos_rad_throttle [number of engines] | Individual copilot throttle control positions. Order is outboard port (left) to outboard starboard. | FWD 0= full aft w/o thrust reversing. Thrust reversing is negative | | | |
| | | controlPos_deg_avgThrottle controlPos_rad_avgThrottle | Average pilot and copilot throttle control position. | FWD 0= full aft w/o thrust reversing. Thrust reversing is negative | | | |
| | | controlPos_deg_avgPropellor controlPos_rad_avgPropellor | Average pilot and copilot propeller blade pitch control position. | FWD 0=flat pitch, Thrust reversing is negative | | | |
| | | controlPos_deg_propellor [number of engines] controlPos_rad_propellor [number of engines] | Individual propeller blade pitch control position. Order is outboard port (left) to outboard starboard. | FWD 0=flat pitch, Thrust reversing is negative | | | |

Annex A Page 40 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 169 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|---|------------|--|---|---|---------------|-----------|-----------|
| Standard naming convention for control surfaces "Pos" indicates a control surface position "Rate" indicates the derivative of the control surface position "Accel" indicates the derivative of the control surface rate "HingeMoment" indicates the hinge moment on the control surface (sign convention = + deflection results in + hinge moment) | | | Control surface positions for a vehicle are often uniquely defined for that vehicle, therefore the: Description Positive Sign Convention Initial Value Min Value Max Value definitions may all change based on the particular vehicle. The table below shall be used as default descriptions and values when they are not otherwise explicitly defined for the vehicle. | | | | |
| δ_{TEF_n} | | controlSurfacePos_deg_TEF [number of trailing edge flap control surfaces] controlSurfacePos_rad_TEF [number of trailing edge flap control surfaces] | Vector of trailing edge flap positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | TED 0 deflection is flap retracted | | | |
| | | controlSurfaceRate_deg_s_TEF [number of trailing edge flap control surfaces] controlSurfaceRate_rad_s_TEF [number of trailing edge flap control surfaces] | Vector of trailing edge flap deflection rates, one for each surface. Order is outboard port (left) to outboard starboard. | TED | | | |
| | | controlSurfaceAccel_deg_s2_TEF [number of trailing edge flap control surfaces] controlSurfaceAccel_rad_s2_TEF [number of trailing edge flap control surfaces] | Vector of trailing edge flap deflection accelerations, one for each surface. Order is outboard port (left) to outboard starboard. | TED | | | |

Annex A Page 41 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 170 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--|------------|---|--|---|---------------|-----------|-----------|
| | | controlSurfaceHingeMoment_ftlbf_TEF [number of trailing edge flap control surfaces] controlSurfaceHingeMoment_Nm_s_TEF [number of trailing edge flap control surfaces] | Vector of the hinge moments on the trailing edge flap, one for each surface. Order is outboard port (left) to outboard starboard. | + = TEU moment (positive deflection results in positive moment) | | | |
| The convention and examples above apply to all control surface positions defined below | | | | | | | |
| δ_{TE_n} | | controlSurfacePos_deg_TEF [number of leading edge flap control surfaces] controlSurfacePos_rad_TEF [number of leading edge flap control surfaces] | Vector of trailing edge flap (TEF) positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | TED | | | |
| δ_{TEF} | | controlSurfacePos_deg_avgTEF controlSurfacePos_rad_avgTEF | Trailing edge flap deflection (TEF). Average for all trailing edge flap surfaces. | TED 0 deflection is flap retracted | | | |
| δ_{rTEF} | | controlSurfacePos_deg_diffTEF controlSurfacePos_rad_diffTEF | Differential trailing edge flap (DTEF) deflection (left deflections {+=TED} -right deflections {+=TED}) | LT TED (RWD moment) | | | |
| δ_{LE_n} | | controlSurfacePos_deg_LEF [number of leading edge flap control surfaces] controlSurfacePos_rad_LEF [number of leading edge flap control surfaces] | Vector of leading edge flap (LEF) positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | LED | | | |
| δ_{LEF} | | controlSurfacePos_deg_avgLEF controlSurfacePos_rad_avgLEF | Leading edge flap/slat deflection. Average for all deflected leading edge flap/slat surfaces. | LED | | | |

Annex A Page 42 of 54


| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 171 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------------------------|------------|--|---|--------------------------------------|---------------|-----------|-----------|
| δ_{LEF} | | controlSurfacePos_deg_diffLEF controlSurfacePos_rad_diffLEF | Differential leading edge flap (LEF) deflection (left deflections-right deflections) | LT LED (RWD moment) | | | |
| δ_{SP_n} | | controlSurfacePos_deg_spoiler [number of spoiler control surfaces] controlSurfacePos_rad spoiler [number of spoiler control surfaces] | Vector of spoiler control surface positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | TEU | | | |
| δ_{SP} | | controlSurfacePos_deg_avgSpoiler controlSurfacePos_rad_avgSpoiler | Spoiler deflection. Average for all deflected spoilers (sum of positions/number of surfaces) | TEU | | | |
| δ_{SP} | | controlSurfacePos_deg_diffSpoiler controlSurfacePos_rad_diffSpoiler | Differential spoiler control surface position (right deflections-left deflections) | RT TEU (RWD moment) | | | |
| δ_{A_n} | | controlSurfacePos_deg_aileron [number of aileron control surfaces] controlSurfacePos_rad_aileron [number of aileron control surfaces] | Vector of aileron control positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | TEU | | | |
| δ_{A} | | controlSurfacePos_deg_diffAileron controlSurfacePos_rad_diffAileron | Differential aileron deflection, (right deflections-left deflections) | Right aileron TEU (RWD moment) | | | |
| $\delta_{A_{tab}_{n,i}}$ | | controlSurfacePos_deg_aileronTab [number of aileron control surfaces, number of tabs] controlSurfacePos_rad_aileronTab [number of aileron control surfaces, number of tabs] | Array of aileron tab control positions (i) for each surface deflected (n). Order is outboard port to outboard starboard | TEU | | | |
| $\delta_{A_{tab}}$ | | controlSurfacePos_deg_avgAileronTab controlSurfacePos_rad_avgAileronTab | Average aileron tab deflection (sum of positions/number of surfaces) | TEU | | | |

Annex A Page 43 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 172 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------------------|------------|--|--|------------------------------------|---------------|-----------|-----------|
| $\delta_{A\text{tab}}$ | | controlSurfacePos_deg_diffAileronTab controlSurfacePos_rad_diffAileronTab | Differential aileron tab deflection (right tab deflections-left tab deflections) | RT Aileron Tab TEU (RWD moment) | | | |
| δ_{r_n} | | controlSurfacePos_deg_rudder [number of rudder control surfaces] controlSurfacePos_rad_rudder [number of rudder control surfaces] | Vector of rudder control positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | TEL | | | |
| δ_r | | controlSurfacePos_deg_avgRudder controlSurfacePos_rad_avgRudder | Average rudder deflection (sum of positions/number of surfaces) | TEL | | | |
| δ_{rR} | | controlSurfacePos_deg_diffRudder controlSurfacePos_rad_diffRudder | Differential rudder deflection (right deflections-left deflections) | RT Rudder TEL (ANR moment) | | | |
| $\delta_{r\text{tab}_{n_j}}$ | | controlSurfacePos_deg_rudderTab [number of rudder control surfaces, number of tabs] controlSurfacePos_rad_rudderTab [number of rudder control surfaces, number of tabs] | Array of rudder tab control positions (i) for each surface deflected (n). Order of tabs is upper to lower. | TEL | | | |
| $\delta_{r\text{tab}}$ | | controlSurfacePos_deg_avgRudderTab controlSurfacePos_rad_avgRudderTab | Average rudder tab deflection (sum of positions/number of surfaces) | RT Rudder Tab TEL (ANR moment) | | | |
| $\delta_{r\text{tab}}$ | | controlSurfacePos_deg_diffRudderTab controlSurfacePos_rad_diffRudderTab | Differential rudder tab deflection (right deflections-left deflections) | RT Rudder Tab TEL (ANR moment) | | | |

Annex A Page 44 of 54


| | | | |
|---|--|--|------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 173 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------------------------|------------|--|---|-----------------------------------|---------------|-----------|-----------|
| δ_{e_n} | | controlSurfacePos_deg_elevator [number of elevator control surfaces] controlSurfacePos_rad_elevator [number of elevator control surfaces] | Vector of elevator (or stabilizer/stabilator) control positions, one for each surface deflected. Order is outboard port (left) to outboard starboard. | TEU | | | |
| δ_e | | controlSurfacePos_deg_avgElevator controlSurfacePos_rad_avgElevator | Average elevator (or stabilizer/stabilator) deflection) (sum of positions/number of surfaces) | TEU | | | |
| δ_{δ_e} | | controlSurfacePos_deg_diffElevator controlSurfacePos_rad_diffElevator | Differential elevator deflection (right deflections-left deflections) | Right control TEU (RWD moment) | | | |
| $\delta_{eTab_{n,j}}$ | | controlSurfacePos_deg_elevatorTab [number of elevator tab control surfaces, number of tabs] controlSurfacePos_rad_elevatorTab [number of elevator tab control surfaces, number of tabs] | Array of elevator (or stabilizer/stabilator) tab positions (j) for each surface (n). Order is outboard port (left) to outboard starboard per control surface. | TEU | | | |
| δ_{eTab} | | controlSurfacePos_deg_avgElevatorTab controlSurfacePos_rad_avgElevatorTab | Average elevator (or stabilizer/stabilator) tab control surface positions (sum of positions/number of surfaces) | TEU | | | |
| $\delta_{\delta_{eTab}}$ | | controlSurfacePos_deg_diffElevatorTab controlSurfacePos_rad_diffElevatorTab | Average differential elevator (or stabilizer/stabilator) tab deflection (right deflections-left deflections) | Right control TEU (RWD moment) | | | |

Annex A Page 45 of 54


| | | | | |
|---|---|--|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | | Document #: NESC-RP-09-00598 | Version: 1.0 |
| | Title: Flight Simulation Model Exchange | | | Page #: 174 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------------|------------|--|--|--|---------------|-----------|-----------|
| δ_{cn} | | controlSurfacePos_deg_canard [number of canard control surfaces] controlSurfacePos_rad_canard [number of canard control surfaces] | Vector of canard control positions, one for each surface. Order is outboard port (left) to outboard starboard. | TED | | 0.0 | |
| δ_c | | controlSurfacePos_deg_avgCanard controlSurfacePos_rad_avgCanard | Average canard position (sum of positions/number of surfaces) | TED | | 0.0 | |
| δ_{gc} | | controlSurfacePos_deg_diffCanard controlSurfacePos_rad_diffCanard | Average differential canard deflection (LEFT deflections- RIGHT deflections) | LEFT control TED (RWD moment) | | | |
| $\delta_{ctab_{nj}}$ | | controlSurfacePos_deg_canardTab [number of canard tab control surfaces, number of tabs] controlSurfacePos_rad_canardTab [number of canard tab control surfaces, number of tabs] | Array of canard tab positions (i) for each surface (n). Order is outboard port (left) to outboard starboard per control surface. | TED | | | |
| δ_{ctab} | | controlSurfacePos_deg_avgCanardTab controlSurfacePos_rad_avgCanardTab | Average canard tab deflection (sum of positions/number of surfaces) | TED | | | |
| δ_{gctab} | | controlSurfacePos_deg_diffCanardTab controlSurfacePos_rad_diffCanardTab | Average differential canard tab deflection (LEFT deflections- RIGHT deflections) | LEFT control TED (RWD moment) | | | |
| δ_{sb} | | controlSurfacePos_deg_speedbrake controlSurfacePos_rad_speedbrake | Speedbrake deflection | Extended | | | |
| δ_{Lgn} | | landingGearPosition [number of landing gear struts] | Vector of landing gear positions, one for each strut. Order is outboard port (left) to outboard starboard. | 0= up and locked 1= full extension with no weight on wheels | | 0.0 | |

Annex A Page 46 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 175 of 343 |

ANSI/AIAA S-119


Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|--|--|--------------------------|---------------|-----------|-----------|
| | | landingGearWeightOnWheels_lbf [number of landing gear struts] landingGearWeightOnWheels_N [number of landing gear struts] | Vector of landing gear weight on wheels, one for each strut. Order is outboard port (left) to outboard starboard. | | | | |
| | | landingGearWheelSpeed_rad_s [number of landing gear struts, number of trucks, number of wheels per truck] | Array of landing gear wheel speeds by strut, one for each strut. Order of struts is outboard port (left) strut, to outboard starboard. Order of trucks is front to rear. Order of wheels on each truck is port to starboard. | | | | |

Table A.8 — Vehicle aerodynamic characteristics

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|----------------|------------|-----------------------------|---|--------------------------|---------------|-----------|-----------|
| C _L | CL | totalCoefficientOfLift | Coefficient Of Lift, Total, includes effects of stores | UP | | | |
| C _D | CD | totalCoefficientOfDrag | Coefficient Of Drag, Total, includes effects of stores | AFT | | | |
| | | aeroBodyForceCoefficient[3] | Vector of total aerodynamic force coefficients in the body coordinate system, comprised of the three components as defined below. | | | | |
| C _X | CX | aeroBodyForceCoefficient_X | X-body Force Coefficient due to aerodynamic loads, includes stores (Body coordinate) | FWD | | | |
| C _Y | CY | aeroBodyForceCoefficient_Y | Y-body Force Coefficient due to aerodynamic loads, includes stores (Body coordinate) | RT | | | |

Annex A Page 47 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 176 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-----------------|------------|--|---|--------------------------|---------------|-----------|-----------|
| C _Z | CZ | aeroBodyForceCoefficient_Z | Z-body Force Coefficient due to aerodynamic loads, includes stores (Body coordinate) | DN | | | |
| | | aeroBodyForce_lbf [3] aeroBodyForce_N [3] | Vector of total aerodynamic forces in the body coordinate system, including stores. Comprised of the three components as defined below. | | | | |
| F _{AX} | FAX | aeroBodyForce_lbf_X aeroBodyForce_N_X | Total X-body Force due to aerodynamic loads, includes stores (Body coordinate) | FWD | | | |
| F _{AY} | FAY | aeroBodyForce_lbf_Y aeroBodyForce_N_Y | Total Y-body Force due to aerodynamic loads, includes stores (Body coordinate) | RT | | | |
| F _{AZ} | FAZ | aeroBodyForce_lbf_Z aeroBodyForce_N_Z | Total Z-body Force due to aerodynamic loads, includes stores (Body coordinate) | DN | | | |
| | | thrustBodyForce_lbf [3] thrustBodyForce_N [3] | Vector of total net propulsion system forces in the body coordinate system (includes installation losses, inlet efficiency and propeller efficiency). Comprised of the three components as defined below. | | | | |
| F _{EX} | FEX | thrustBodyForce_lbf_X thrustBodyForce_N_X | Total net engine thrust Force, X-body axis | FWD | | | |
| F _{EY} | FEY | thrustBodyForce_lbf_Y thrustBodyForce_N_Y | Total net engine thrust Force , Y-body axis | RT | | | |
| F _{EZ} | FEZ | thrustBodyForce_lbf_Z thrustBodyForce_N_Z | Total net engine thrust Force, Z-body axis | DN | | | |

Annex A Page 48 of 54


| | | | | |
|---|---|--|-------------------------|------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | | Document #: | Version: |
| | | | NESC-RP-09-00598 | 1.0 |
| Title: | | | Page #: | |
| Flight Simulation Model Exchange | | | 177 of 343 | |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|-------------------|------------|--|---|--------------------------|---------------|-----------|-----------|
| | | gearBodyForce_lbf [3] gearBodyForce_N [3] | Vector of total landing gear ground reaction forces in the body coordinate system. Does NOT include aerodynamic forces on the landing gear that are included in <code>aeroBodyForce</code> defined above. Comprised of the three components as defined below. | | | | |
| F _{GX} | FGX | gearBodyForce_lbf_X gearBodyForce_N_X | Total landing gear ground reaction force, X-body axis | FWD | | | |
| F _{GY} | FGY | gearBodyForce_lbf_Y gearBodyForce_N_Y | Total landing gear ground reaction force, Y-body axis | RT | | | |
| F _{GZ} | FGZ | gearBodyForce_lbf_Z gearBodyForce_N_Z | Total landing gear ground reaction force, Z-body axis | DN | | | |
| | | totalBodyForce_lbf [3] totalBodyForce_N [3] | Vector of total forces in the body coordinate system. Includes all forces exerted upon the aircraft. Comprised of the three components as defined below. | | | | |
| F _{xTOT} | FX | totalBodyForce_lbf_X totalBodyForce_N_X | Total Forces On a/c, X-body axis | FWD | | | |
| F _{yTOT} | FY | totalBodyForce_lbf_Y totalBodyForce_N_Y | Total Forces On a/c, Y-body axis | RT | | | |
| F _{zTOT} | FZ | totalBodyForce_lbf_Z totalBodyForce_N_Z | Total Forces On a/c, Z-body axis | DN | | | |
| | | aeroBodyMomentCoefficient [3] | Vector of total aerodynamic moment coefficients in the body coordinate system, including stores. Comprised of the three components as defined below. | | | | |
| C _i | CLL | aeroBodyMomentCoefficient_Roll | Total Aerodynamic Rolling Moment Coefficient including stores. Moment about the X-body axis | RWD | | | |

Annex A Page 49 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 178 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|---|--------------------------|---------------|-----------|-----------|
| C_m | CLM | aeroBodyMomentCoefficient_Pitch | Total Aerodynamic Pitching Moment Coefficient, including stores. Moment about the Y-body axis | ANU | | | |
| C_n | CLN | aeroBodyMomentCoefficient_Yaw | Total Aerodynamic yawing Moment Coefficient, including stores. Moment about the Z-body axis | ANR | | | |
| | | aeroBodyMoment_ftlbf [3] aeroBodyMoment_Nm [3] | Vector of total aerodynamic moments in the body coordinate system, including stores. Referenced to the moment reference center. Comprised of the three components as defined below. | | | | |
| L_A | TAL | aeroBodyMoment_ftlbf_Roll aeroBodyMoment_Nm_Roll | Total Aerodynamic Rolling moment (including attached stores), about the X-body axis | RWD | | | |
| M_A | TAM | aeroBodyMoment_ftlbf_Pitch aeroBodyMoment_Nm_Pitch | Total Aerodynamic pitching moment (including attached stores), about the Y-body axis | ANU | | | |
| N_A | TAN | aeroBodyMoment_ftlbf_Yaw aeroBodyMoment_Nm_Yaw | Total Aerodynamic yawing moment (including attached stores), about the Z-body axis | ANR | | | |
| | | thrustBodyMoment_ftlbf [3] thrustBodyMoment_Nm [3] | Vector of total net propulsion system moments in the body coordinate system (includes installation losses, inlet efficiency and propeller efficiency). Referenced to the moment reference center. Comprised of the three components as defined below. | | | | |
| L_E | TEL | thrustBodyMoment_ftlbf_Roll thrustBodyMoment_Nm_Roll | Total Engine Rolling Moment, about the X-body axis | RWD | | | |
| M_E | TEM | thrustBodyMoment_ftlbf_Pitch thrustBodyMoment_Nm_Pitch | Total Engine pitching Moment, about the Y-body axis | ANU | | | |

Annex A Page 50 of 54


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 179 of 343 |

ANSI/AIAA S-119

Annex A. Standard Variable Names

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|------------------|------------|---|---|--------------------------|---------------|-----------|-----------|
| N _E | TEN | thrustBodyMoment_ftlbf_Yaw thrustBodyMoment_Nm_Yaw | Total Engine yawing Moment, about the X-body axis | ANR | | | |
| | | landingGearBodyMoment_ftlbf [3] landingGearBodyMoment_Nm [3] | Vector of total landing gear ground reaction moments in the body coordinate system. Referenced to the moment reference center. Does NOT include aerodynamic moments on the landing gear that are included in <i>aeroBodyMoment</i> defined above. Comprised of the three components as defined below. | | | | |
| L _G | TGL | landingGearBodyMoment_ftlbf_Roll landingGearBodyMoment_Nm_Roll | Total Landing Gear Rolling Moment, about the X-body axis | RWD | | | |
| M _G | TGM | landingGearBodyMoment_ftlbf_Pitch landingGearBodyMoment_Nm_Pitch | Total Landing gear Pitch Moment, about the Y-body axis | ANU | | | |
| N _G | TGN | landingGearBodyMoment_ftlbf_Yaw landingGearBodyMoment_Nm_Yaw | Total Landing Gear Yawing Moment, about the Z-body axis | ANR | | | |
| | | totalBodyMoment_ftlbf [3] totalBodyMoment_Nm [3] | Vector of total moments in the body coordinate system. Referenced to the moment reference center. Includes all moments exerted upon the aircraft. Comprised of the three components as defined below. | | | | |
| L _{TOT} | TTL | totalBodyMoment_ftlbf_Roll totalBodyMoment_Nm_Roll | Total Rolling Moment, about the X-body axis | RWD | | | |
| M _{TOT} | TTM | totalBodyMoment_ftlbf_Pitch totalBodyMoment_Nm_Pitch | Total Pitching Moment, about the Y-body axis | ANU | | | |
| N _{TOT} | TTN | totalBodyMoment_ftlbf_Yaw totalBodyMoment_Nm_Yaw | Total Yawing Moment, about the Z-body axis | ANR | | | |

Annex A Page 51 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 180 of 343 |


ANSI/AIAA S-119

Annex A. Standard Variable Names

Table A.9 — Simulation control parameters

| Symbol | Short Name | Full Variable Name | Description | Positive Sign Convention | Initial Value | Min Value | Max Value |
|--------|------------|---|--|--------------------------|---------------|-----------|-----------|
| | TIME | simDuration_s | Time Since Start Of Operate Mode | NSC | | | |
| | | deltaTime_s[number of different integration step sizes] | Vector of Integration step sizes | | | | |
| | | simDate | Date simulated. Date at the start of the simulation is used. (Not the date the simulation run was made) Type yyyy-mm-dd | | | | |
| | | simTime | Simulated time of day based on 24 hours Zulu. Type hh:mm:ss.ss | | | | |
| | | productionDate | Date the simulation run was made (Not the simulated date [simDate]) Type yyyy-mm-dd | | | | |

Annex A Page 52 of 54

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 181 of 343 |

ANSI/AIAA
Annex A. Standard Variable Names

S-119

References

GRAM 07.

Justus, C.G.; and Leslie, F. W.: "The NASA MSFC Earth Global Reference Atmospheric Model—2007 Version" NASA TM-2008-215581

For symbols:

ISO 1151-1 : 1988

ISO 1151-2 : 1985


ISO 1151-4 : 1994(E)

ISO 1151-5 : 1987

Not all symbols presented above are defined by ISO. This document attempts to make them consistent where similar.

For Time and Dates:

ISO 8601:2000

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 182 of 343 |


ANSI/AIAA

S-119

Annex A. Standard Variable Names

DAVE-ML Website (Informative)

The “official” DAVE-ML site is <http://daveml.org/>. This link contains all DAVE-ML documentation and links and information on DAVE-ML tools and applications. Additional information is available at <http://www.aiaa.org/>

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 183 of 343 |

Appendix C. XML Document Type Definition file for S-119 markup: DAVEfunc.dtd

```
<?xml version="1.0" encoding="UTF-8"?><!--
```

```
=====
```

Dynamic Aerospace Vehicle Exchange DTD
Function Data Representation

Version: 2.0 Release Candidate 3

This DTD module is identified by these PUBLIC and SYSTEM identifiers:

PUBLIC "-//AIAA//DTD for Flight Dynamic Models - Functions 2.0//EN"
SYSTEM "http://daveml.org/DTDs/2p0RC3/DAVEfunc.dtd"

Developed by:

American Institute of Aeronautics and Astronautics (AIAA)
Modeling & Simulation Technical Committee
Simulation Modeling Standards Subcommittee

Contact information:

E. Bruce Jackson <mailto:bruce.jackson@nasa.gov>
Bruce L. Hildreth <mailto:bhildreth@jfti.com>
Persistent DAVE-ML contact <mailto:info@daveml.org>
<http://daveml.org>

Purpose:

Proposed standard for exchanging dynamic models of aerospace vehicles, including aero, engine, gear, inertia, and control models.

This preliminary version defines static models typically associated with aerodynamic subsystem models, but can be used to describe any non-linear multi-dimensional function.

Status:


In development. Direct comments to above contacts.

```
===== -->
<!-- =====
```

Acknowledgments:

The editors would like to acknowledge the contributions, encouragement and helpful suggestions from Dennis Linse (originally SAIC, now Vuelo Software Analysis), Jon Berndt (Jacobs Sverdrup), Brent York (Indra), Bill Cleveland (NASA Ames), Geoff Brian (Australia's DSTO), J. Dana McMinn (NASA Langley), Peter Grant (UTIAS), Giovanni A. Cignoni (University of Pisa), Daniel M. Newman (formerly Ball Aerospace, now Quantitative Aeronautics), Hilary Keating (Fortburn Pty. Ltd.), Riley Rainey (SDS International), Jeremy Furtek (Delphi Research) and Randy Brumbaugh (Indigo Innovations).

```
===== -->
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | |
| | | Page #: 184 of 343 | |

```

<!-- =====
      Include the MathML2 DTD for any math markup
===== -->

<!ENTITY % mathml2 PUBLIC "-//W3C//DTD MathML 2.0//EN"
      "http://www.w3.org/Math/DTD/mathml2/mathml2.dtd">
%mathml2;

<!-- ++++++ -->
<!--                      Level 0 Elements                      -->
<!-- ++++++ -->

<!-- =====
      Root element is DAVEfunc, composed of a file header element
      followed by one or more variable definitions and zero or more
      breakpoint definitions, gridded or ungridded table definitions,
      and function elements.
===== -->


<!ELEMENT DAVEfunc (
    fileHeader,
    variableDef+,
    breakpointDef*,
    griddedTableDef*,
    ungriddedTableDef*,
    function*,
    checkData?
)
>
<!-- ATTLIST DAVEfunc
      xmlns      CDATA      #FIXED  'http://daveml.org/2010/DAVEML'
>

<!-- ++++++ -->
<!--                      Level 1 Elements                      -->
<!-- ++++++ -->

<!-- =====
      The header element requires at least one author and a creation date;
      optional content includes version indicator, description,
      references, and modification records.
===== -->

<!ELEMENT fileHeader (
    author+,
    (creationDate | fileCreationDate),
    fileVersion?,
    description?,
    reference*,
    modificationRecord*,
    provenance*
)
>
<!-- ATTLIST fileHeader
      name      CDATA      #IMPLIED

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 185 of 343 |

```

>
<!-- =====
variableDef elements provide wiring information (i.e., they
identify the input and output signals used by these function
blocks). They also provide MathML content markup to indicate any
calculation required to arrive at the value of the variable,
using other variables as inputs. The variable definition can
include statistical information regarding the uncertainty of the
values which it might take on, when measured after any
calculation is performed. Information about the reason for
inclusion or change to this element can be included in an
optional provenance sub-element.

===== -->

<!ELEMENT variableDef (
  description?,
  (provenance | provenanceRef)?,
  calculation?,
  (isInput | isControl | isDisturbance)?,
  isState?,
  isStateDeriv?,
  isOutput?,
  isStdAIAA?,
  uncertainty?
)
>
<!ATTLIST variableDef
  name          CDATA      #REQUIRED
  varID          ID        #REQUIRED
  units          CDATA      #REQUIRED
  axisSystem     CDATA      #IMPLIED
  sign           CDATA      #IMPLIED
  alias          CDATA      #IMPLIED
  symbol         CDATA      #IMPLIED
  initialValue    CDATA      #IMPLIED
>

<!ELEMENT variableRef EMPTY>
<!ATTLIST variableRef
  varID          IDREF     #REQUIRED
>


<!-- =====

A breakpointDef lists gridded table breakpoints.
Since these are separate from function data they may be reused.

===== -->

<!ELEMENT breakpointDef (
  description?,
  bpVals
)
>
<!ATTLIST breakpointDef
  name          CDATA      #IMPLIED
  bpID          ID        #REQUIRED
  units         CDATA      #IMPLIED
>

```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | |
| | | Page #: 188 of 343 | |

```

>
<!-- =====
creationDate is simply a string with a date in it. We
follow ISO 8601 and use dates like "2004-01-02" to refer to
January 2, 2004.
===== -->

<!ELEMENT creationDate EMPTY>
<!-- =====
date          CDATA    #REQUIRED
>

<!-- =====
fileCreationDate is simply a string with a date in it. We
follow ISO 8601 and use dates like "2004-01-02" to refer to
January 2, 2004. Its use is now deprecated in favor of the
simpler creationDate.
===== -->

<!ELEMENT fileCreationDate EMPTY>
<!-- =====
date          CDATA    #REQUIRED
>

<!-- =====
This is a string describing, in some arbitrary text, the version
identifier for this function description.
===== -->

<!ELEMENT fileVersion (#PCDATA)>


<!-- =====
The description element is a textual description of an
entity. The full UNICODE character set is supported by XML but
may not be available in all processing applications.
===== -->

<!ELEMENT description (#PCDATA)>

<!-- =====
The presence of the isOutput element indicates that this
variable should be forced to be an output, even if it is used
internally as an input elsewhere. Otherwise, the processing
program may assume a signal defined with a calculation and used
subsequently in the model is only an internal signal.
===== -->

<!ELEMENT isOutput EMPTY>

```

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 189 of 343 |

```

<!-- =====
    The presence of an isState element indicates that this variable
    is one of possibly multiple state variables in a dynamic model;
    this tells the processing entity that this is the output of an
    integrator (for continuous models) or a discretely updated state
    (for discrete models).
    ===== -->

<!ELEMENT isState EMPTY>

<!-- =====
    The presence of an isStateDeriv element indicates that this
    variable is one of possibly several state derivative variables
    in a dynamic model; this tells the processing entity that this
    is the output of an integrator (for continuous models only).
    ===== -->

<!ELEMENT isStateDeriv EMPTY>

<!-- =====
    The presence of an isInput element indicates that this variable
    is an input signal to the model.
    ===== -->

<!ELEMENT isInput EMPTY>

<!-- =====
    The presence of an isControl element indicates that this signal
    is a simulation control parameter used to vary the operation of
    the model, e.g. the time step size. Such parameters should be
    ignored when performing linear model extraction (for example)
    and should not significantly modify the dynamic behavior of the
    model.
    ===== -->


<!ELEMENT isControl EMPTY>

<!-- =====
    The presence of an isDisturbance element indicates that this
    signal is an external disturbance input to the model and can be
    ignored when performing linear model extraction (for
    example). Such parameters should not significantly modify the
    nominal dynamic behavior of the model.
    ===== -->

<!ELEMENT isDisturbance EMPTY>

<!-- =====

```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 191 of 343 |

```

<!ATTLIST modificationRecord
    modID      ID      #REQUIRED
    date       CDATA   #REQUIRED
    refID      IDREF   #IMPLIED
>

<!-- =====
A single modification event may have more than one documented
reference. This element can be used in place of the refID
attribute in a modificationRecord to record more than one
refIDs, pointing to the referenced document.
===== -->

<!ELEMENT extraDocRef EMPTY>
<!ATTLIST extraDocRef
    refID      IDREF   #REQUIRED
>

<!-- =====
The provenance element describes the history or source of the
model data and includes author, date, and zero or more
references to documents and modification records.
===== -->

<!ELEMENT provenance (
    author+,
    (creationDate | functionCreationDate),
    documentRef*,
    modificationRef*,
    description?
)
>
<!ATTLIST provenance
    provID      ID      #IMPLIED
>

<!-- =====
When the provenance of a set of several data is identical, the
first provenance element should be given a provID and referenced by
later provenanceRef elements.
===== -->

<!ELEMENT provenanceRef EMPTY>
<!ATTLIST provenanceRef
    provID      IDREF   #REQUIRED
>

<!-- =====
An independentVarPts element is a simple white space- or
comma-separated list of breakpoints and contains a mandatory
varID identifier as well as optional name, units, and sign
convention attributes.

An optional extrapolate attribute describes how to extrapolate
the output value when the input value exceeds specified values
(default is 'neither,' meaning the value of the table is held
Page 9

```



| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 193 of 343 |

table (supporting discrete, linear, cubic or quadratic splines). There are three different discrete options: 'discrete' means nearest-neighbor, with an exact mid-point value being rounded in the positive direction; 'floor' means the function takes on the value associated with the next (numerically) higher independent breakpoint as soon as original value is exceeded; and 'ceiling' means the function holds the value associated with each breakpoint until the next (numerically) higher breakpoint value is reached by the independent argument. The default interpolation attribute value is 'linear.'

This element allows reuse of common breakpoint values for many tables but with possible differences in interpolation or extrapolation for each use.

```

===== -->

<!ELEMENT independentVarRef EMPTY>
<!ATTLIST independentVarRef
    varID      IDREF      #REQUIRED
    min        CDATA      #IMPLIED
    max        CDATA      #IMPLIED
    extrapolate (neither | min | max | both) #IMPLIED
    interpolate (discrete | floor | ceiling | linear | quadraticspline |
cubicSpline) #IMPLIED
>

<!-- =====
A dependentVarRef ties the output of a function to a signal name
defined previously in a variable definition.
===== -->

<!ELEMENT dependentVarRef EMPTY>
<!ATTLIST dependentVarRef
    varID      IDREF      #REQUIRED
>

<!-- =====
A functionDefn defines how function is represented in one of two
possible ways: gridded (implies breakpoints) or ungridded (with
explicit independent values for each point).
===== -->


<!ELEMENT functionDefn (griddedTableRef | griddedTableDef | griddedTable |
ungriddedTableRef | ungriddedTableDef | ungriddedTable)>
<!ATTLIST functionDefn
    name      CDATA      #IMPLIED
>

<!-- ++++++----- -->
<!-- ++++++----- Level 3 Elements ----- -->
<!-- ++++++----- -->

<!ELEMENT address (#PCDATA)>

<!-- =====

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 194 of 343 |

Used to provide contact information about an author. Use contactInfoType to differentiate what information is being conveyed and contactLocation to denote location of the address.

```

===== -->

<!ELEMENT contactInfo (#PCDATA)>
<!ATTLIST contactInfo
  contactInfoType (address | phone | fax | email | iname | web) #IMPLIED
  contactLocation (professional | personal | mobile) #IMPLIED
>

<!-- =====

functionCreationDate is simply a string with a date in it. We
follow ISO 8601 and use dates like "2004-01-02" to refer to
January 2, 2004. Its use is now deprecated in favor of the
simpler creationDate.

===== -->

<!ELEMENT functionCreationDate EMPTY>
<!ATTLIST functionCreationDate
  date CDATA #REQUIRED
>

<!ELEMENT documentRef EMPTY>
<!ATTLIST documentRef
  docID IDREF #IMPLIED
  refID IDREF #REQUIRED
>

<!ELEMENT modificationRef EMPTY>
<!ATTLIST modificationRef
  modID IDREF #REQUIRED
>


<!ELEMENT griddedTableRef EMPTY>
<!ATTLIST griddedTableRef
  gtID IDREF #REQUIRED
>

<!ELEMENT griddedTable (
  breakpointRefs,
  confidenceBound?,
  dataTable
)
>
<!ATTLIST griddedTable
  name CDATA #IMPLIED
>

<!ELEMENT ungriddedTableRef EMPTY>
<!ATTLIST ungriddedTableRef
  utID IDREF #REQUIRED
>

<!ELEMENT ungriddedTable (
  confidenceBound?,
  dataPoint+
)
>
<!ATTLIST ungriddedTable

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 195 of 343 |

```

    name          CDATA    #IMPLIED
>
<!-- =====
    Contains a description of the inputs and outputs, and possibly internal
values, of a DAVE-ML
    model in a particular instant of time.
    ===== -->

<!ELEMENT staticShot (
    description?,
    (provenance | provenanceRef)?,
    checkInputs,
    internalValues?,
    checkOutputs
)
>
<!ATTLIST staticShot
    name          CDATA    #REQUIRED
    refID         IDREF    #IMPLIED
>

<!-- ++++++ -->
<!-- Level 4 Elements -->
<!-- ++++++ -->

<!-- =====
    The breakpointRefs elements tie the independent variable names
    for the function to specific breakpoint values defined earlier.
    ===== -->

<!ELEMENT breakpointRefs (bpRef+)>


<!-- =====
    The confidenceBound element is used to declare the confidence
    interval associated with the data table. This is a place-holder
    and will be removed in a future version of DAVE-ML.
    ===== -->

<!ELEMENT confidenceBound EMPTY>
<!ATTLIST confidenceBound
    value          CDATA    #REQUIRED
>

<!-- =====
    The uncertainty element is used in function and parameter
    definitions to describe statistical variance in the possible
    value of that function or parameter value. Only Gaussian
    (normal) or uniform distributions of continuous random variable
    distribution functions are supported.
    ===== -->

<!ELEMENT uncertainty (normalPDF | uniformPDF)>

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 196 of 343 |

```
<!ATTLIST uncertainty
  effect      (additive | multiplicative | percentage | absolute) #REQUIRED
>
```

```
<!-- =====
```

The dataTable element is used by gridded tables where the indep. variable values are implied by breakpoint sets. Thus, the data embedded between the dataTable element tags is expected to be sorted ASCII values of the gridded table, wherein the last independent variable listed in the function header varies most rapidly.

The table data point values are specified as comma- or white space-separated values in conventional floating-point notation (0.93638E-06) in a single long sequence as if the table had been unraveled with the last-specified dimension changing most rapidly. Line breaks are to be ignored. Comments may be embedded in the table to promote [human] readability, with appropriate escaping characters.

A dataTable element can also be used in an uncertainty element to provide duplicate uncertainty bound values.

```
===== -->
```

```
<!ELEMENT dataTable (#PCDATA)>
```

```
<!-- =====
```

The dataPoint element is used by ungridded tables to list the values of independent variables that are associated with each value of dependent variable. For example:

```
<dataPoint>
  0.1, -4.0, 0.2      <!-- Mach, alpha, CL ->
</dataPoint>
<dataPoint>
  0.1, 0.0, 0.6      <!-- Mach, alpha CL ->
</dataPoint>
```

Each data point may have associated with it a modification tag to document the genesis of that particular point. No requirement on ordering of independent variables is implied. Since this is an ungridded table, the interpreting application is required to handle what may be unsorted data.


```
===== -->
```

```
<!ELEMENT dataPoint (#PCDATA)>
<!ATTLIST dataPoint
  modID      IDREF      #IMPLIED
>
```

```
<!-- =====
Specifies the contents of the input vector for the given check case.
```

```
===== -->
```

```
<!ELEMENT checkInputs (signal+)>
```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 197 of 343 |

```

<!-- =====
Provides a set of all internal variable values to assist in debugging
recalcitrant
implementations of DAVE-ML import tools.
===== -->

<!ELEMENT internalValues (signal+)>

<!-- =====
Specifies the contents of the output vector for the given check
case.
===== -->

<!ELEMENT checkOutputs (signal+)>

<!-- ++++++----- -->
<!-- Level 5 Elements -->
<!-- ++++++----- -->

<!-- =====
The bpRef element provides references to a previously-defined
breakpoint set so breakpoints can be defined separately from,
and reused by, several data tables.
===== -->


<!ELEMENT bpRef EMPTY>
<!ATTLIST bpRef
    bpID      IDREF    #REQUIRED
>

<!-- =====
In a normally distributed random variable, a symmetrical
distribution of given standard deviation is assumed about the
nominal value (which is given elsewhere in the parent element).

The correlatesWith sub-element references other functions or
variables that have a linear correlation to the current
parameter or function. The correlation sub-element specifies the
correlation coefficient and references the other function or
variable whose random value helps determine the value of this
parameter.
===== -->

<!ELEMENT normalPDF (
    bounds,
    correlatesWith*,
    correlation*
)
>
<!ATTLIST normalPDF
    numSigmas CDATA    #REQUIRED
>

```


| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 198 of 343 |

```

<!-- =====
      In a uniformly distributed random variable, the value of the
      parameter has equal likelihood of assuming any value within the
      (possibly asymmetric, implied by specifying two) bounds, which
      must bracket the nominal value (which is given elsewhere in the
      parent element).
===== -->

<!-- ELEMENT uniformPDF (bounds+)>

<!-- =====
      This element contains some description of the statistical limits
      to the values the citing parameter element might take on. This
      can be in the form of a scalar value, a private dataTable, or a
      variableRef. In the more common instance, this element will
      either be a scalar constant value or a simple table whose
      dimensions must match the parent nominal function table and
      whose independent variables are identical to the nominal
      table. It is also possible that this limit be determined by an
      independent variable, either previously defined or defined
      in-line with this element. It does not make sense to have a
      dataTable cited if this bounds element is associated with
      anything other than an identically shaped function table.
===== -->

<!-- ELEMENT bounds (#PCDATA | dataTable | variableDef | variableRef)*>


<!-- =====
      When present, this element indicates the parent function or
      variable is correlated with the referenced other function or
      variable in a linear sense. This alerts the application that
      the random number used to calculate this function's or variable's
      immediate value will be used to calculate another function's or
      variable's value.
===== -->

<!-- ELEMENT correlatesWith EMPTY>
<!-- ATTLIST correlatesWith
      varID      IDREF      #REQUIRED
>

<!-- =====
      When present, this element indicates the parent function or
      variable is correlated with the referenced other function or
      variable in a linear sense and gives the correlation
      coefficient for determining this function's random value based
      upon the correlating function(s)'s random value.
===== -->

<!-- ELEMENT correlation EMPTY>
<!-- ATTLIST correlation
      varID      IDREF      #REQUIRED

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 199 of 343 |

```

> corrCoef CDATA #REQUIRED
>
<!-- =====
This element is used to document the name, ID, value, tolerance,
and units of measure for check-cases. When used with checkInputs
or checkOutputs, the signalName sub-element must be present
(since check cases are viewed from "outside" the model); when
used in an internalValues element, the varID sub-element should
be used to identify the signal by its model-unique internal
reference. When used in a checkOutputs vector, the tol element
must be present. Tolerance is specified as a maximum absolute
difference between the expected and actual value.

The signalID sub-element is now deprecated in favor of the more
consistent varID.

===== -->
<!ELEMENT signal (
  ((
    signalName,
    signalUnits
  ) | (
    (varID | signalID)
  )),
  signalValue,
  tol?
)
>

<!-- ++++++ -->
<!-- Level 6 Elements -->
<!-- ++++++ -->
<!-- =====
Used inside a checkCase element to specify the input or output
variable name


===== -->
<!ELEMENT signalName (#PCDATA)>

<!-- =====
Used to specify the input or output varID. Now deprecated; reuse
of varID is best practice.

===== -->
<!ELEMENT signalID (#PCDATA)>

<!-- =====
Used to specify the input or output varID. Replaces earlier
signalID element.

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 200 of 343 |

```

===== -->
<!ELEMENT varID (#PCDATA)>

<!-- =====
      Used inside a checkCase element to specify the units-of-measure
      for an input or output variable, for verification of proper
      implementation of a model.
===== -->

<!ELEMENT signalUnits (#PCDATA)>


<!-- =====
      Used to give the current value of an internal signal or
      input/output variable, for verification of proper implementation
      of a model.
===== -->

<!ELEMENT signalValue (#PCDATA)>

<!-- =====
      This element specifies the allowable tolerance of error in an
      output value such that the model can be considered verified. It
      is assumed all uncertainty is removed in performing the model
      calculations. Tolerance is specified as a maximum absolute
      difference between the expected and actual value.
===== -->

<!ELEMENT tol (#PCDATA)>

```

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 201 of 343 |

Appendix D. Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML) Reference Manual

Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML) Reference

Version 2.0 (Release Candidate 3)
2010-05-07

AIAA Modeling and Simulation Technical
Committee [<https://info.aiaa.org/tac/ASG/MSTC>]

E. Bruce Jackson, NASA Langley Research Center <bruce.jackson@nasa.gov>


Abstract

The Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML) is a text-based file format intended for encoding the principal elements of a flight simulation model for an aerospace vehicle. It is based on two other open standards: the Extensible Markup Language (XML) version 1.1 and the Mathematical Markup Language (MathML) version 2.0, both products of the World Wide Web Consortium. DAVE-ML defines additional grammar (markup elements) to provide a domain-specific language capable of aerospace flight dynamics modeling, verification, and documentation.

This markup language represents the encoding format for BSR/AIAA S-119 Flight Dynamic Model Exchange Standard [AIAA10].

This is a draft version of the reference manual for DAVE-ML syntax and markup. DAVE-ML syntax is specified by the `DAVEfunc.dtd` Document Type Definition (DTD) file; the version number above refers to the version of the `DAVEfunc.dtd`.


DAVE-ML is an open standard, being developed by an informal team of American Institute of Aeronautics and Astronautics (AIAA) members. Contact the author above for more information or comments regarding refinement of DAVE-ML.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 202 of 343 |

DAVE-ML 2


Table of Contents

| | |
|--|----|
| 1. Changes | 4 |
| 1.1. RC3 changes | 4 |
| 1.1.1. RC3 DTD changes | 4 |
| 1.1.2. RC3 non-DTD changes | 5 |
| 1.2. RC2 changes | 6 |
| 1.3. RC1 changes | 7 |
| 1.4. 1.9b3 changes | 8 |
| 1.5. 1.9b2 changes | 8 |
| 1.6. 1.8b1 changes | 8 |
| 1.7. 1.7b1 changes | 9 |
| 1.8. 1.6b1 changes | 9 |
| 1.9. 1.5b3 changes | 9 |
| 1.10. 1.5b2 changes | 10 |
| 2. Introduction | 11 |
| 3. Purpose | 12 |
| 4. Background | 13 |
| 4.1. Existing standards | 13 |
| 4.2. DAVE-ML proposal | 13 |
| 4.3. DAVE-ML applications | 13 |
| 5. Supporting technologies | 15 |
| 6. Major elements | 16 |
| 6.1. DAVEfunc | 16 |
| 6.2. DAVEfunc overview | 18 |
| 6.2.1. fileHeader overview | 21 |
| 6.2.2. variableDef overview | 23 |
| 6.2.3. breakpointDef overview | 30 |
| 6.2.4. griddedTableDef overview | 31 |
| 6.2.5. ungriddedTableDef overview | 34 |
| 6.2.6. function overview | 38 |
| 6.2.7. checkData overview | 43 |
| 6.3. Interpolation | 46 |
| 6.4. Statistics | 49 |
| 6.5. Conventions | 55 |
| 6.5.1. Point order | 55 |
| 6.5.2. Moment Reference | 56 |
| 6.5.3. Subsystem decomposition | 56 |
| 6.5.4. Date format | 56 |
| 6.5.5. Sign conventions | 56 |
| 6.5.6. Units | 56 |
| 6.5.7. XML Identifiers | 57 |
| 6.5.8. Namespace | 57 |
| 6.6. Future | 58 |
| 7. More information | 59 |
| 8. Element references and descriptions | 60 |
| 8.1. Alphabetical list of elements | 60 |
| 8.2. Element descriptions | 62 |

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 203 of 343 |

DAVE-ML 2

| | |
|------------------|-----|
| References | 131 |
| Index | 133 |

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 204 of 343 |

DAVE-ML 2

1. Changes to this document

This section contains a list of changes during the development of the DAVE-ML DTD.

1.1. Changes since version 2.0RC2

This section outlines changes to the DTD and this reference manual since version 2, release candidate 2, was released in October 2008.

The changes are divided into *structural* changes to the DTD and *non-structural* changes to the DTD and reference manual.

1.1.1. DTD structural changes since version 2.0RC2

- Corrected the DTD to require at least one `staticShot` child element of the `checkData` element.
- Changed the DTD logic for inclusion of provenance information for elements `griddedTableDef`, `ungriddedTableDef`, `function`, `checkData`, and `staticShot` from


```
( provenance? | provenanceRef? )
```

to

```
( provenance | provenanceRef )?
```

which is the more correct way to display an optional selection from two choices. However, use of `provenance` or `provenanceRef` is now deprecated for `checkData` elements as described in the non-structural changes below; this change was made for consistency with the other elements that have provenance information.

- Added optional, mutually exclusive flag elements `isInput`, `isControl`, and `isDisturbance` to conform with the latest draft of [AIAA10]. These flags are intended to help clarify the role of all defined variables and to assist in analyses such as linear model extraction.
- Changed the Uniform Resource Identifier (URI) for the `atan2` function definition to the `daveml.org` domain.
- Changed SYSTEMID to reflect new `daveml.org` domain; changed PUBLIC ID from NASA to AIAA.
- In the DTD, the default DAVE-ML namespace definition was added to the top-level `DAVEfunc` element to observe a best-practice for XML DTDs, at the suggestion of Dan Newman.
- In the DTD and reference manual, changed the `bpVals` elements to allow white space separation of values in addition to comma separation (which has always been the case for the `dataTable` element). Ditto for `dependentVarPts` and `independentVarPts`. This may cause a problem for some existing parsers.


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 205 of 343 |

DAVE-ML 2

No other changes have been made to the DAVE-ML grammar since 2.0RC2, but this version of the DTD and reference manual include clean-up of a number of inconsistencies (found by Dennis Linse and Trey Arthur) between the reference manual and element descriptions, as noted below.

1.1.2. Non-structural DTD and reference manual changes since version 2.0RC2

- Corrected second ungridded table definition example and CLRUD0 function example; reformatted page references from [xx] to (p. xx) in the PDF reference manual, thanks to suggestions by Dennis Linse.
- Amplified and elaborated on possible values for `interpolate` and `extrapolate` attributes for independent variables of function definitions.
- Added an index to the reference manual.
- Removed the sign convention list as this is now in the overlying AIAA draft standard, S-119 [AIAA10].
- Added clarification that, while uncertainty can be applied in multiple places in the model (including input, calculations, functions, and outputs), it is probably not a good practice to do so.
- Changed the non-dimensional signal units-of-measure indication from blank or ND to 'nd', in accordance with the latest draft standard [AIAA10]; removed plus sign from front of sign convention since it doesn't always apply and is redundant to the definition.
- Added references to earlier standards papers by B. Hildreth [Hildreth94], [Hildreth98].
- Cleaned up formatting in the element descriptions found in Section 8.2 (p. 62) corrected the grammar in the BNF descriptions of the major elements within this text.
- Added two sentences to the description of the calculation element, explaining how to tie variables in the model to the MathML expression via the MathML content identifier (`ci`) element. Thanks to Missy Hill and Curtis Zimmerman for pointing out the lack of explanation.
- Changed email address for B. Hildreth; added persistent email at daveml.org; changed default Uniform Resource Locator (URL) to daveml.org
- Changed the description of `bounds` element in the DTD to remove out-of-date reference to `[un]griddedTable[Def]Ref` since this is no longer supported. In the reference manual, removed a misleading second `bounds` element for the `uniformPDF` element case and added notes to imply the presence of `PCDATA` (either one or two, depending on the case). Thanks to Dan Newman for prompting this review and change.
- Did more DTD clean-up to remove redundant 'optional' specifiers on elements and attributes; made the 'internal identifier' descriptions consistent throughout the DTD and reference manual; tweaked the style of the reference pages in the reference manual; fixed poor grammar in the DTD; replaced parentheses with brackets in the BNF syntax in the reference manual for comments to avoid confusion; reformatted the reference pages in the manual for readability; and added references to W3C on-line documentation where necessary. Thanks to Dennis Linse for encouraging the correction of these long-standing inconsistencies and distractions.


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 206 of 343 |

DAVE-ML 2

- Put editorial comments in BNF syntaxes in braces ({} to avoid confusion with parentheses, which are used to indicate a choice. Thanks to Dennis Linse for the catch.
- In the DTD, a sentence was added to the description of the deprecated `fileCreationDate` element and a similar description was added to the deprecated `functionCreationDate` element mentioning that both of them have been deprecated in version 2.0. The clarification was made after near-simultaneous suggestions from both Trey Arthur and Dan Newman.
- Added a paragraph about the `alias` attribute of the `variableDef` element; it's a valid attribute but was missing an explanation. Thanks to Trey Arthur for catching this long-standing omission.
- Changed the definition of `atan2` so that the input arguments are not limited to ± 1 and are not referred to as 'sine' and 'cosine' to better match ANSI C. Thanks to Dan Newman for catching this inconsistency.
- Corrected typographical errors in `fileHeader`, `variableDef`, `griddedTableDef`, `ungriddedTableDef`, and `function` element schematic overview syntaxes in sections 6.2.1-6.2.6. Thanks to Dennis Linse for catching these errors.
- Added a sentence about the `tol` sub-element being an absolute difference to remove ambiguity over its interpretation.
- In the reference manual syntax layout, moved the `provenance` and `provenanceRef` sub-elements out of `checkData` and into `staticShot` sub-elements since `checkData`, a singleton place-holder, doesn't warrant a description but each `staticShot` does. `provenance` and `provenanceRef` are still in the DTD for `checkData` but only for backwards compatibility; their use in a `checkData` element is deprecated and may be removed in a future version. Thanks to Dennis Linse for prompting this needed change.
- Added a note to documentRef `docID` attribute that it is deprecated. Thanks to Dennis Linse for catching this omission.
- Removed the redundant "optional" in the description of `reference` element's `xlink:href` attribute. Added the constant value for attributes `xmlns:xlink` and `xlink:type`. Expanded the somewhat terse description of this element. Thanks to Dennis Linse for this correction and other helpful suggestions.

1.2. Changes since version 2.0RC1

- Tweaked examples and syntaxes to match the 2.0 RC 2 DTD. Cleaned up a couple of figures and incorporated several new reference citations. Added interpolation paragraph.
- Deprecated `signalID` used for internal signals in check-case data in favor of the more consistent `varID` (which meant the introduction of a formal `varID` element) and made the specification of `signalUnits` sub-element mandatory for input and output signals for consistency. Thanks to Dan Newman for helping solidify the thinking about this issue.
- Changed examples in this text to use updated AIAA variable names to match a revised (but unpublished) draft standard of September 2008. Changed many 'examples' to 'excerpts' to

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 207 of 343 |


DAVE-ML 2

emphasize the missing portions of a valid DAVE-ML file. Corrected units in check-case examples to match the draft AIAA standard.

- Removed the `symmetric` attribute of the `uniformPDF` sub-element; this attribute was redundant as symmetric distribution is implied with a single `bounds` sub-element, and asymmetric is implied by two `bounds` sub-elements. Kudos to Dan Newman and Dennis Linse for catching the inconsistent examples and for suggesting this convention.
- Corrected the DTD by reversing the definition of the `floor` and `ceiling` values of the `interpolate` attribute of the `independentVarPts` element; also corrected the correlated uncertainty example. Thanks to Dan Newman for catching both of these problems in 2.0 RC1.
- Corrected the DTD so that only one `checkData` element is allowed (but it can have multiple different `staticShot` test conditions). Thanks to Dan and Dennis for reporting this inconsistency between the reference manual and the DTD.
- Added a `description` sub-element to the `staticShot` element in response to a suggestion by Dennis Linse; and added a typical description to example listings.
- Added a section about namespaces and removed the hard link in the DTD that incorrectly set the namespace for the `calculation` element.
- Added new multi-purpose `creationDate` element to replace the single-purpose `fileCreationDate` and `functionCreationDate` elements, at the suggestion of Dennis Linse of SAIC. `fileCreationDate` and `functionCreationDate` are now deprecated.
- Corrected descriptions of `ungriddedTableDef` and `griddedTableDef` to reflect the possible use of an internal `function` element; previously the descriptions implied that these elements were only specified external to functions and thus the `utID` and `gtID` attributes, respectively, were required. Thanks to Dennis Linse for the correction.
- Depicted `provenanceRef` as an option to the `provenance` sub-element for `griddedTableDef`, `ungriddedTableDef`, and `function` elements in the narrative part of this manual (it was described correctly in the reference section). Also added both `provenance` and `provenanceRef` as optional sub-elements of the `variableDef` and `checkData` elements. Thanks to Dennis Linse for the correction.
- Added '[Deprecated]' to the description of `griddedTable`, `ungriddedTable`, and `confidenceBound` elements for consistency; these were previously deprecated but not marked clearly in each element's 'purpose' section. Thanks to Dennis Linse for the suggestion.
- Updated the acknowledgment paragraph of the DTD; significantly reformatted the .PDF version of this document, and added section numbers to all versions.

1.3. Changes since version 1.9b3

- Added `ceiling` and `floor` enumeration selections to `interpolate` attribute of `independentVarPts` and `independentVarRef` elements at the suggestions of Geoff Brian, Giovanni Cignoni, Randy Brumbaugh, and Dan Newman.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 208 of 343 |

DAVE-ML 2

- Added five uncertainty examples.
- Cleaned up all FIXME and BUG notes.
- Corrected and expanded the labels on the DAVE-ML excerpt figure.

1.4. Changes since version 1.9b2


- Corrected link to the DAVE-ML exchange test [Jackson04] paper.
- Added `discrete enumeration selection to interpolate` attribute of `independentVarPts` and `independentVarRef` elements at the suggestion of Geoff Brian, Australian Defence Science and Technology Organisation (DSTO).
- Added a section and a `variableDef` example on extending the MathML-2 function set with *atan2*.
- Removed all `xns` attributes from examples.
- Emphasized that it is a good practice to provide `variableDefs` in sorted sequence.

1.5. Changes since version 1.8b1

- Added a `quadraticSpline` enumerated value to the `interpolate` attributes of the `independentVarPts` and `independentVarRef` elements (in response to a request from Geoff Brian of DSTO) and fixed a typographical error in `cubicSpline` attribute string. Added reference to Wikipedia article on spline interpolation [http://en.wikipedia.org/wiki/Spline_interpolation].
- Added a `classification` attribute to the `reference` element and added a `date` attribute to the `modificationRecord` element, at the suggestion of Geoff Brian of DSTO.
- Added 2D and 3D ungridded table examples and figures and corrected a typographical error in the ungridded table definition syntax (thanks to Dr. Peter Grant of U. Toronto's UTIAS and Geoff Brian of DSTO).
- Reintroduced `<!ENTITY>` to include MathML-2 DTD (complete) in the body of this DTD. This entity definition quietly went away in version 1.6 due to a misunderstanding of the proper way to include external DTDs. It was reintroduced to assist with validating parsers.
- Added a `description` sub-element to the `provenance` element, so the `provenance` entry can contain more information about change justification documents and made `provenance` or `provenanceRef` acceptable sub-elements to `variableDef` and `checkData` elements at the request of Geoff Brian of DSTO.

1.6. Changes since version 1.7b1

- Renamed `docID` attribute to `refID` in the `modificationRecord` so the attribute name is consistent; the `docID` attribute is deprecated but remains in place for compatibility with older documents.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 209 of 343 |

DAVE-ML 2

- Added `correlatesWith` and `correlation` sub-elements of `uncertainty` element to allow for multiple-dimensioned linear correlation of uncertainty of selected functions and variables.
- Added a new element, `contactInfo`, to replace the single `address` element. This format supports multiple ways to indicate how to contact the author of a document or reference. `address` is deprecated but is retained for backwards compatibility. This element also replaces the `email` and `xns` attributes of `author`.
- Fixed a typographical error in `ungriddedTableRef` element: incorrect `gtID` attribute corrected to `utID`.
- Allowed multiple `author` elements wherever only one had been allowed before.
- Added a new tag, `isStdAIAA`, to indicate that a `variableDef` refers to one of the standard AIAA variables.
- Removed `[un]griddedTable[Ref|Def]` sub-elements of the `confidenceBound` element since this leads to circular logic.
- Changed `SYSTEMID` to reflect new `daveml.nasa.gov` domain availability.
- Removed true email from examples to protect privacy of individual contributors.
- Added a new attribute, `interpolate`, to the `independentVarPts` element to indicate whether the table interpolation should be linear or cubic spline in the given dimension [modified to include quadratic in version 1.9].
- Added a new tag, `isState`, to indicate that a `variableDef` refers to a state variable in the model.
- Added a new tag, `isStateDeriv`, to indicate that a `variableDef` refers to a state derivative variable in the model.

1.7. Changes since version 1.6b1


Added `checkData` and associated elements. Added `description` sub-element to `reference` element.

1.8. Changes since version 1.5b3

Added an `uncertainty` element. Emphasized MathML-2 content markup over presentation markup. Fixed several grammatical and typographical errors and added figure 1. Added ISO 8601 (Dates and Times) reference.

1.9. Changes since version 1.5b2

- Added Bill Cleveland (NASA Ames Research Center's SimLab) and Brent York (NAVAIR's Manned Flight Simulator) to the acknowledgments section, to thank them for their pioneering initial trials of DAVE-ML.


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 210 of 343 |

DAVE-ML 2

- Added `provenanceRef` element and changed all parents (specifically `function`, `griddedTableDef` and `ungriddedTableDef` elements) of provenance elements to enable them to use a `provenanceRef` reference instead to eliminate duplicate provenance elements.
- Realization dawned that there was little difference between `griddedTables` and `griddedTableDefs` but that the latter was more flexible (ditto `ungriddedTables` and `ungriddedTableDefs`). By making the `gtID` and `utID` attributes 'implied' instead of 'required,' we can use the `Def` versions in both referenced-table and embedded-table functions. Thus the original `griddedTable` and `ungriddedTable` elements have been marked as 'deprecated.' They are still supported in this DTD for backwards compatibility but should be avoided in future use. The easiest way to modify older DAVE-ML models would be to rename all `griddedTables` as `griddedTableDefs`.

1.10. Changes since version 1.5b

- Fixed typographical errors pointed out by Bill Cleveland.
- Added `fileVersion` element to `fileHeader` element, so each version of a particular DAVEfunc model can be uniquely identified. Format of the version identifier is undefined.
- Added an email attribute to the `author` element. The Extensible Name Service (xns [<http://www.xns.org>]) standard does not appear to be catching on as rapidly as hoped, so a static e-mail link will have to do for now, at least until the replacement XRI technology is more widely adopted.
- Added a mandatory `varID` attribute to both `independentVarPts` and `dependentVarPts` so these can be associated with an input and output signal name (`variableDef`), respectively.
- Added an optional `extraDocRef` element to the `modificationRecord` element so more than one document can be associated with each modification event. If only one document needs to be referenced, use of the optional `refID` in the `modificationRecord` itself will suffice.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 211 of 343 |

DAVE-ML 2

2. Introduction


This document describes the format for DAVE-ML model definition files. DAVE-ML is a proposed standard format for the interchange of aerospace vehicle flight dynamics models. The intent of DAVE-ML is to significantly expedite the process of re-hosting a simulation model from one facility to another and function as an improved method to promulgate changes to a particular model between various facilities.

DAVE-ML is based on the Extensible Markup Language (XML), a World-Wide Web Consortium (W3C) standard. More information on XML is available here [<http://www.w3.org/XML/>].

The exchange of aerospace vehicle flight dynamics models may derive many benefits from the application of XML in general, and DAVE-ML in particular:

- Provides a human-readable text description of the model
- Provides an unambiguous machine-readable model description, suitable for conversion into programming language or direct import into object-oriented data structures at run-time
- Allows use of the same source file for computer-aided design and real-time piloted simulation
- Based on open, non-proprietary, standards that are language- and facility-independent
- Allows inclusion of statistical properties, such as confidence bounds and uncertainty ranges, suitable for Monte Carlo or other statistical analysis of the model
- Complies with emerging AIAA simulation data standards
- Represents a self-contained, complete, archivable data package, including references to reports, wind-tunnel tests, author contact information, and data provenance
- Is self-documenting and easily convertible to on-line and hard-copy documentation

A more complete discussion on the benefits and design of DAVE-ML can be found at the DAVE-ML web site: <http://daveml.org> [<http://daveml.org>]

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 212 of 343 |

DAVE-ML 2

3. Purpose

DAVE-ML is intended to encode (for exchange and long-term archive) an entire flight vehicle dynamic simulation data package, as is traditionally done in initial delivery and updates to engineering development, flight training, and accident investigation simulations. It is intended to provide a programming-language-independent representation of the aerodynamic, mass/inertia, landing gear, propulsion, and guidance, navigation and control laws for a particular vehicle.


Traditionally, flight simulation data packages are often a combination of paper documents and data files on magnetic or optical media. This collection of information is very much vendor-specific and is often incomplete or inconsistent. Many times, the preparing facility makes incorrect assumptions about how the receiving facility's simulation environment is structured. As a result, the re-hosting of the dynamic flight model by the receiving facility can take weeks or longer as the receiving facility staff learns the contents and arrangement of the data package, the model structure, the various data formats, and variable names/units/sign conventions. The staff then spends additional time running check-cases (if any were included in the transmittal) and tracking down inevitable differences in results.

There are obvious benefits to automating most of this tedious, manual process. Often, when a pair of facilities has already exchanged one model, the transmission of another model is much faster since the receiving facility will probably have devised some scripts and processes to convert the data (both model and check-case data).

The purpose of DAVE-ML is to develop a common exchange format for these flight dynamic models. The advantage gained is to enable any simulation facility or laboratory, after having written a DAVE-ML import and/or export script, to automatically receive and/or transmit such packages (and updates to those packages) rapidly with other DAVE-ML-compliant facilities.

To accomplish this goal, the DAVE-ML project is starting with the bulkiest part of most aircraft simulation packages: the aerodynamics model. This initial version of DAVE-ML can be used to transport a complete aerodynamics model, including descriptions of the aerodynamic build-up equations and data tables, and include references to the documentation about the aerodynamics model and check-case data. This format also lends itself to any static subsystem model (i.e. one that contains no state vector) such as the mass and inertia model, or a weapons load-out model, or perhaps a navigational database. The only requirement is that model outputs must be unambiguously defined in terms of inputs, with no past history (state) information required.

DAVE-ML forms the encoding portion of the Flight Simulation Model Exchange Standard, BSR/AIAA S-119-2010 (currently in draft form). More information is available at the S-119 web site [AIAA10].

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 213 of 343 |

DAVE-ML 2

4. Background

The idea of a universally understood flight dynamics data package has been discussed for at least two decades within the AIAA technical committees [Hildreth94], [Hildreth98]. There have been proposals in the past to standardize on Fortran as well as proprietary, vendor-specified modeling packages, including graphical ones. The National Aerospace Plane (NASP) Program, under the guidance of Larry Schilling of NASA Dryden Flight Research Center, developed a hybrid Web- and secure-FTP-based system for exchanging NASP subsystem models as well as a naming convention for variables, file names, and other simulation components in the early 1990s. Some other simulation standards have subsequently been proposed by the AIAA and are under active consideration at this writing [AIAA10].

4.1. Existing standards

The AIAA has published a Recommended Practice concerning sign conventions, axes systems, and symbolic notation for flight-vehicle models [AIAA92].

The AIAA Modeling and Simulation Technical Committee has prepared a draft standard for the exchange of simulation modeling data. This includes a methodology for accomplishing the gradual standardization of simulation model components, a mechanism for standardizing variable names within math models, and proposed Hierarchical Data Format 5 (HDF5) as the data format. This document is included as an Annex to the standard [AIAA01], [AIAA03], [AIAA10].

4.2. DAVE-ML proposal


In a 2002 AIAA paper, Jackson and Hildreth proposed using XML to exchange flight dynamic models [Jackson02]. This paper gave outlines for how such a standard could be accomplished, and provided a business justification for pursuing such a goal.

The 2002 proposal included several key aspects from the draft standard, including allowing use of a standard variable-name convention and data table schema and including traceability for each data point back to a referenced document or change order.

In a subsequent paper, Jackson, Hildreth, York and Cleveland [Jackson04] reported on the results of a demonstration using DAVE-ML to exchange two aerodynamic models between simulation facilities, showing the feasibility of the idea.


4.3. Recent applications

Several successful applications of DAVE-ML have been reported. These include the adoption of DAVE-ML by the Australian DSTO for threat models [Brian05] and the U.S. Navy for their Next Generation Threat System [Hildreth08]. Import tools to allow the direct use of DAVE-ML models (without recompilation) in real-time piloted simulations have been reported by NASA Langley Research Center (LaRC) [Hill07] and at NASA Ames Research Center (ARC). Some interest has been generated within NASA's Orion Project as well [Acevedo07]. Other applications include TSONT, a trajectory optimization tool ([Durak06]) and aircraft engine simulations ([Lin04]).

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 214 of 343 |

DAVE-ML 2

DAVE-ML format for models has also been supported by the GeneSim [<http://genesim.sourceforge.net>] Project, which is providing open-source utility programs that realize a DAVE-ML model in object-oriented source code such as C++, Java and C#.


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 215 of 343 |

DAVE-ML 2

5. Supporting technologies

DAVE-ML relies on MathML, version 2.0, to define mathematical relationships. MathML-2 is an XML grammar for describing mathematics as a basis for machine-to-machine communication. It is used in DAVE-ML to describe relationships between variables and function tables and may also be used for providing high-quality typeset documentation from the DAVE-ML source files. More information is available at the MathML-2 home web page, found at <http://www.w3.org/Math/>.

MathML-2 provides a mostly complete set of mathematical functions, including trigonometric, exponential and switching functions. One function that is available in most programming languages and computer-aided design tools but is missing from MathML-2 is the two-argument arctangent function which provides a continuous angle calculation by comparing the sine and cosine components of a 2D coordinate set. DAVE-ML provides a means of extending MathML-2 for a predefined set of functions (currently only the *atan2* function is defined). Thus, a DAVE-ML-compliant processing tool should recognize this extension (which is accomplished by using the MathML-2 *csymbol* element). See Section 6.2.2 (p. 23) for a discussion and Example 6 (p. 29).

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 216 of 343 |

DAVE-ML 2

6. Major elements

At present, only one major element of DAVE-ML has been defined: the function definition element, or `DAVEfunc`. `DAVEfunc` is used to describe static models such as aerodynamic and inertia/mass models, where an internal state is not included. Static check-cases can also be provided for verification of proper implementation.

Other major elements are envisioned to describe dynamic portions of the vehicle model (such as propulsion, landing gear, control systems, etc.) and dynamic check-case (time history) data. Ultimately DAVE-ML should be capable of describing a complete flight-dynamics model with sufficient data to validate the proper implementation thereof.

6.1. The `DAVEfunc` major element

The `DAVEfunc` element contains both data tables and equations for a particular static model. A `DAVEfunc` element is broken into six components: a file header, variable definitions, breakpoint definitions, table definitions, function definitions and optional check-cases. This decomposition reflects common practice in engineering development flight-simulation models in which the aerodynamic database is usually captured in multi-dimensional, linearly interpolated function tables. The inputs to these tables are usually state variables of the simulation (such as Mach number or angle-of-attack). The outputs from these interpolated tables are combined to represent forces and moments acting on the vehicle due to aerodynamics.


It is possible, using `DAVEfunc` and `MathML-2` elements, to completely define an aerodynamic model without use of function tables (by mathematical combinations of input variables, such as a polynomial model) but this is not yet common in the American flight-simulation industry.

A `fileHeader` element is included to give background and reference data for the represented model.

Variables, or more properly *signals*, are used to route inputs and calculations through the subsystem model into outputs. Each variable is defined with a `variableDef` element. Variables can be thought of as parameters in a computer program or signal paths on a block diagram. They can be inputs to the subsystem model, constant values, outputs from the model, and/or the results of intermediate calculations. Variables must be defined for each input and output of any function element as well as any input or output of the subsystem represented. `MathML-2` [<http://www.w3.org/Math>] *content* markup can be used to define constant, intermediate, or output variables as mathematical combination of constant values, function table outputs, and other variables, but any *presentation* markup is not required and should be ignored by the processing application (except as required to generate documentation). Variables also represent the current value of a function (the `dependentVariableDef` in a function definition) so the output of functions can be used as inputs to other variables or functions.

Breakpoint definitions, captured in `breakpointDef` elements, consist of a list of monotonically increasing floating-point values separated by commas or white space. These sets are referenced by "gridded" function table definitions and may be referenced by more than one function definition.

Function table definitions, described by `griddedTableDef` and `ungriddedTableDef` elements, generally contain the bulk of data points in an aerodynamics model, and typically

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 217 of 343 |


DAVE-ML 2

represent a smooth hyper-surface representing the value of some aerodynamic non-dimensional coefficient as a function of one or more vehicle states (typically Mach number, angle-of-attack, control surface deflection, and/or angular body rates). These function tables can be either "gridded," meaning the function has a value at every intersection of each dimension's breakpoint, or "ungridded," meaning each data point has a specified coordinate location in n-space. The same table can be reused in several functions, such as a left- and right-aileron moment contribution.

Function definitions (described by `function` elements) connect breakpoint sets and data tables to define how an output signal (or dependent variable) should vary with one or more input signals (or independent variables). The valid ranges of input-signal magnitudes, along with extrapolation requirements for out-of-range inputs, can be defined. There is no limit to the number of independent variables, or function dimensionality, of the function.

Check-case data (described by a single `checkData` element) can be included to provide information to automatically verify the proper implementation of the model by the recipient. Multiple check-cases can (and should) be specified using multiple `staticShot` test-case definitions, as well as optional internal signal values within the model to assist in debugging an instantiation of the model by the recipient.

Figure 1 (p. 18) contains excerpts from an example model, showing five of the six major parts of a DAVE-ML file.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 218 of 343 |

DAVE-ML 2

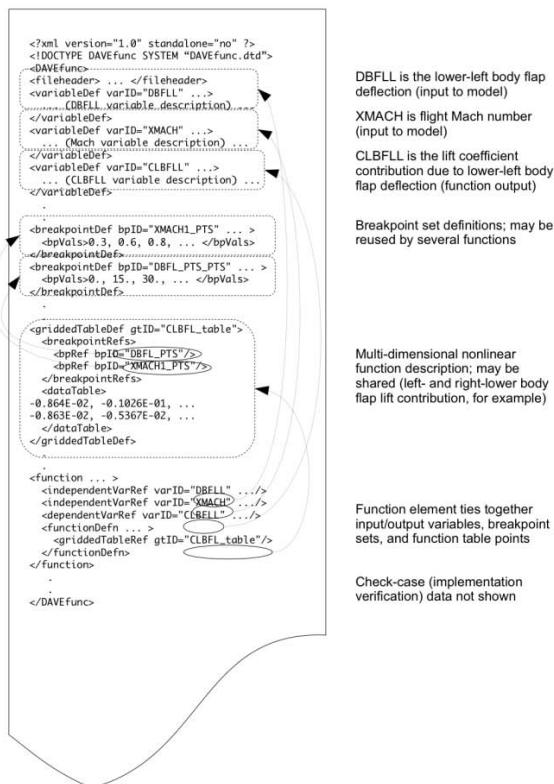



Figure 1. Excerpts from an example DAVE-ML file

A simpler version of a `function` is available in which the dependent variable breakpoint values and dependent output values are specified directly inside the `function` body. This may be preferred for models that do not reuse function or breakpoint data.

A third form of `function` is to give the gridded table values or ungridded table values inside the `function` body, but refer to externally defined breakpoint sets. This allows reuse of the breakpoint sets by other functions but keeps the table data private.

6.2. Schematic overview of DAVEfunc

Shown below are schematic overviews of the various elements currently available in `DAVEfunc`. Each element is described in detail in Section 8 (p. 60) later in this document. The following key is used to describe the elements and associated attributes.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 219 of 343 |

DAVE-ML 2

```

Key:
  elementname : mandatory_attributes, [optional_attributes]
               mandatory_single_sub-element
               optional_single_sub-element?           {editorial comment}
               ( choice_1_sub-element | choice_2_sub-element )
               zero_or_more_sub-elements*
               one_or_more_sub-elements+
               (character data) implies UNICODE text information

```

The **DAVEfunc** element has six possible sub-elements:


```

DAVEfunc :
  fileHeader
  variableDef+
  breakpointDef*
  griddedTableDef*
  ungriddedTableDef*
  function*
  checkData?

```

DAVEfunc sub-elements:

| | |
|------------------------|--|
| fileHeader | This mandatory element contains information about the origin and development of this model. |
| variableDef | <p>Each DAVEfunc model must contain at least one signal path (such as a constant output value). Each input, output or internal signal used by the model must be specified in a separate variableDef.</p> <p>A signal can have only a single origin (an input block, a calculation, or a function output) but can be used (referenced) more than once as an input to one or more functions, signal calculations, and/or as a model output.</p> <p>In DAVE-ML 2.0, all signals are real and scalar.</p> <p>The variableDefs should appear in calculation order; that is, a variableDef should not appear before the definitions of variables upon which it is dependent. This is good practice since doing so avoids a circular reference. If a variable depends upon the output (dependentVar) of a function it can be assumed that dependence has been met, since function definitions appear later in the DAVEfunc element.</p> |
| breakpointDef | A DAVEfunc model can contain zero, one, or more breakpoint set definitions. These definitions can be shared among several gridded function tables. Breakpoint definitions can appear in any order. |
| griddedTableDef | A DAVEfunc model can contain zero, one, or more gridded nonlinear function table definitions. Each table |

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 220 of 343 |

DAVE-ML 2

must be used by multiple function definition if desired for efficiency. Alternatively, some or all functions in a model can specify their tables internally with an embedded `griddedTableDef` element.

A gridded function table contains dependent values, or data points, corresponding to the value of a function at the intersection of one or more breakpoint sets (one for each dimension of the table). The independent values (coordinates or breakpoint sets) are not stored within the gridded table definition but are referenced by the parent function. This allows a function table to be supported by more than one set of breakpoint values (such as left- and right-aileron deflections).

`ungriddedTableDef`

A DAVEfunc model can contain zero, one, or more ungridded nonlinear function table definitions. Unlike a rectangularly gridded table, an ungridded table specifies data points as individual sets of independent and dependent values. Each table must be used by at least one but can be used by multiple function definitions if necessary for efficiency. Alternatively, functions can retain their tables internally with a `ungriddedTable` element without sharing the table values with other functions.

Ungridded table values are specified as a single (unsorted) list of independent variable (input) values and associated dependent variable (output) values. While the list is not sorted, the order of the independent variable inputs is important and must match the order given in the parent function. Thus, functions that share an ungridded table definition must have the same ordering of independent variables.


The method of interpolating the ungridded data is not specified.

`function`

A function ties together breakpoint sets (for gridded-table nonlinear functions), function values (either internally or by reference to table definitions), and the input- and output-variable signal definitions, as shown in Figure 1 (p. 18) Functions also include provenance, or background history, of the function data such as wind tunnel test or other source information.

`checkData`

This optional element contains information allowing the model to be automatically verified after implementation by the receiving party.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 221 of 343 |

DAVE-ML 2

An example of each of these sub-elements is given below. Complete descriptions of each element in detail are found in Section 8 (p. 60).

6.2.1. The file header element

The `fileHeader` element contains information about the source of the data contained within the `DAVEfunc` major element, including the author, creation date, description, reference information, and modification history.


```

fileHeader : [name]
  author+ : name, org, [email]
    contactInfo* : [contactInfoType, contactLocation]
      {text describing contact information for author}
  creationDate : date {in ISO 8601 YYYY-MM-DD format}
  fileVersion? : [file version identifier]
  description? : [textual description of model]
  reference* : refID, author, title, date, [classification, accession, href]
    description? : [textual information about reference]
  modificationRecord* : modID, date, [refID]
    author+ : name, org, [email]
      contactInfo* : [contactInfoType, contactLocation]
        {text describing contact information for author}
    description? : [textual description of modification]
  extraDocRef* : refID
  provenance* :
    author+ : name, org, [email]
      contactInfo* : [contactInfoType, contactLocation]
        {text describing contact information for author}
    creationDate : date {in ISO 8601 YYYY-MM-DD format}
    documentRef* : [docID,] refID
    modificationRef* : modID
    description? : [textual description of the background of the model]

```

fileHeader sub-elements:

| | |
|---------------------------|---|
| <code>author</code> | Name, organization, optional email address and other contact information for each author. |
| <code>creationDate</code> | Creation date of this file. See Section 6.5.4 (p. 56) for the recommended format for encoding dates. |
| <code>fileVersion</code> | A string that indicates the version of the document. No convention is specified for the format, but a good practice would include an automated revision number from a version control system. |
| <code>description</code> | An optional but recommended text description: what does this DAVE-ML file represent? |
| <code>reference</code> | An optional list of one or more references with a document-unique ID (must begin with alpha character), author, title, date, and optional accession and URL of the |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 222 of 343 |

DAVE-ML 2

reference. This sub-element can include a description of the reference.

modificationRecord

An optional list of one or more modifications with optional reference IDs, as well as author information and descriptions for each modification record. These modifications are referred to by individual function tables and/or data points, using the AIAA modification letter convention. If more than one document is associated with the modification, multiple sub-element extraDocRefs may be used in place of the modificationRecord's refID attribute.

provenance

An optional list of one or more provenance elements allows the author to describe the source and history of the data within this model. Since the model may be constructed from several sources, more than one provenance may be provided, one for each source of data. Use of a provID attribute in the fileHeader is unnecessary since this provenance applies to the entire model unless otherwise specified.

Example 1. An excerpt with an example of a fileHeader element

```

<!-- ===== --> ❶
<!-- FILE HEADER ----- -->
<!-- ===== -->


<fileHeader> ❷
  <author name="Bruce Jackson" org="NASA Langley Research Center">
    <contactInfo contactInfoType='address' contactLocation='professional'>
      MS 308 NASA, Hampton, VA 23681
    </contactInfo>
    <contactInfo contactInfoType='email' contactLocation='professional'>
      Bruce.Jackson@nospam.nasa.gov
    </contactInfo>
  </author>
  <creationDate date="2003-03-18"/> ❸

  <fileVersion>$Revision: 1.24 $</fileVersion> ❹

  <description>
    Version 2.0 aero model for HL-20 lifting body, as described in
    NASA TM-107580. This aero model was used for HL-20 approach and
    landing studies at NASA Langley Research Center during 1989-1995
    and for follow-on studies at NASA Johnson Space Center in 1994
    and NASA Ames Research Center in 2001. This DAVE-ML version was
    created in March 2003 by Bruce Jackson to demonstrate DAVE-ML.
  </description>

  <reference refID="REF01" ❺
    author="Jackson, E. Bruce; Cruz, Christopher I. & and Ragsdale, W. A."
    title="Real-Time Simulation Model of the HL-20 Lifting Body"
    accession="NASA TM-107580"
    date="1992-07-01"
  </reference>

```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 223 of 343 |

DAVE-ML 2

```

/>

<reference refID="REF02"
  author="Cleveland, William B. <nospan@mail.arc.nasa.gov>"
  title="Possible Typo in HL20_aero.xml"
  accession="email"
  date="2003-08-19"
/>

<modificationRecord modID="A" refID="REF02"> ❹
  <author name="Bruce Jackson" org="NASA Langley Research Center">
    <contactInfo contactInfoType='address' contactLocation='professional'>
      MS 308 NASA, Hampton, VA 23681
    </contactInfo>
  </author>
  <description>
    Revision 1.24: Fixed typo in CLRUD0 function description which
    gave dependent signal name as "CLRUD1." Bill Cleveland of NASA
    Ames caught this in his xml2ftp script. Also made use of 1.5b2
    fileHeader fields and changed date formats to comply with
    convention.
  </description>
</modificationRecord>

</fileHeader>

```


- ❶ Use of comments make models more readable by humans.
- ❷ Start of the fileHeader element.
- ❸ Creation date of file, in ISO-8601 format. See Section 6.5.4 (p. 56)
- ❹ In this example, the revision number is automatically inserted by a version control system.
- ❺ All documents referenced by notation throughout the file should be described in the fileHeader as reference elements.
- ❻ All modifications made to the contents of this file should be listed in the fileHeader as modificationRecord sub-elements for easy reference by later modificationRef elements.

6.2.2. The variable definition element

The variableDef element is used to define each constant, parameter, or variable used within or generated by the defined subsystem model. It contains attributes including the variable name (used for documentation), an internal and unique varID identifier (used for linking inputs, functions and outputs), the units of measure of the variable, and optional axis system, sign convention, alias, and symbol declarations. Optional sub-elements include a written text description and a mathematical description, in MathML-2 content markup, of the calculations needed to derive the variable from other variables or function table outputs. Optional sub-element isOutput, serves to indicate an intermediate calculation that should be brought out to the rest of the simulation. Another optional sub-element, isStdAIAA, indicates the variable name is defined in the AIAA simulation standards document. Another optional sub-element, uncertainty, captures the statistical properties of a (normally constant) parameter.

Other optional sub-elements are provided to identify inputs, disturbances, and simulation control parameters, as well as the ability to identify a variable as a state or state derivative for linear model purposes.

There must be a single variableDef for each and every input, output or intermediate constant or variable within the DAVEfunc model.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 224 of 343 |

DAVE-ML 2


```

variableDef : name, varID, units, [axisSystem, sign, alias, symbol, initialValue]
description? :
  {description character data}
(
  provenanceRef : provID
OR
  provenance : [provID]
    author+ : name, org, [email]
    contactInfo* : {contactInfoType, contactLocation}
    {text describing contact information}
    creationDate : date {in YYYY-MM-DD format}
    documentRef* : [docID,] refID
    modificationRef* : modID
    description?
)?
calculation? :
  math {defined in MathML-2 DTD}
(isInput | isControl | isDisturbance)?
isState?
isStateDeriv?
isOutput?
isStdAIAA?
uncertainty? : effect
  (normalPDF : numSigmas) | (uniformPDF : bounds+)

```

variableDef attributes:

| | |
|------------|---|
| name | A UNICODE name for the variable (may be the same string as the varID). |
| varID | An internal identifier that is unique within the file. |
| units | The units-of-measure for the signal, using the AIAA standard units convention [AIAA10]. |
| axisSystem | An optional indicator of the axis system (body, inertial, etc.) in which the signal is measured. See [AIAA10] or Section 6.5 (p. 55) below for recommended practice for nomenclature. |
| sign | An optional indicator of which direction is considered positive (+RWD, +UP, etc.). See [AIAA10] or the section on Section 6.5 (p. 55) below for recommended practice for abbreviations. |
| alias | An optional, facility-specific variable name, perhaps used in the equations of motion or control system model, that does not conform to the AIAA standard for variable names. Use of this attribute is discouraged for portability reasons. |
| symbol | A UNICODE Greek symbol for the signal [to be superseded with more formal MathML or TeX element in a later release]. |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 225 of 343 |

DAVE-ML 2

`initialValue` An optional initial value for the parameter. This is normally specified for constant parameters only.

variableDef sub-elements:

`description` An optional text description of the variable.

`provenance` The optional provenance element allows the author to describe the source and history of the data within this `variableDef`. Alternatively, a `provenanceRef` reference can be made to a previously defined `provenance`.

`calculation` An optional container for the MathML-2 content markup that describes how this variable is calculated from other variables or function table outputs. This element contains a single `math` element which is defined in the MathML-2 markup language [<http://www.w3.org/Math>].

A MathML-2 calculation can include both constants (using the content numeric `cn` element) and references to other variables internal to the parent `DAVEfunc` description. The variables (which can include the output, or dependent variable of a function table) are identified using its `varID` attribute string in the appropriate MathML content identifier (`ci`) element of the expression.


Examples of MathML expressions appear later in this reference.

`isInput` This optional element, if present, signifies that this variable is an input to the model, such as a pilot inceptor deflection or Mach number. Useful for linear model extraction tools. It must not be the result of a calculation or be cited as the dependent variable of a function.

`isControl` This optional element, if present, signifies that this variable is a simulation control parameter, such as a trim flag or simulation time step measurement. Simulation control parameters should have no influence on the dynamic behavior of the model and should be ignored by a linear model extraction tool.

`isDisturbance` This optional element, if present, signifies that this variable represents an external disturbance input to the model; this is useful for linear model extraction tools to partition this input separately from the other model inputs.

`isOutput` This optional element, if present, signifies that this variable needs to be passed as an output. How this is

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 226 of 343 |

DAVE-ML 2

accomplished is up to the implementer. Unless specified by this element, a variable is considered an output only if it is the result of a calculation or function AND is not used elsewhere in the DAVEfunc.

`isStdAIAA`

This optional element, if present, signifies that this variable is one of the standard AIAA simulation variable names that are defined as Annex A to [AIAA10]. Such identification should make it easier for the importing process to connect this variable (probably an input or output of the model) to the appropriate variable to/from the user's simulation framework.

`isState`

This optional element, if present, signifies that this variable serves as a state of the model.

`isStateDeriv`

This optional element, if present, signifies that this variable serves as a state derivative of the model.

`uncertainty`

This optional element, if present, describes the uncertainty of this parameter. See the section on Statistics below for more information about this element.


Example 2. An example of two `variableDef` elements defining input signals

In this example, two input variables are defined: XMACH and DBFLL. These two variables are inputs to a table lookup function shown in Example 11 (p. 41) below.

```
<!-- ===== VARIABLE DEFINITIONS ===== -->
<!-- ===== -->

<!-- ===== -->
<!-- Input variables -->
<!-- ===== -->

<variableDef name="mach" varID="XMACH" units="nd" symbol="M">
  <description>
    Mach number (dimensionless)
  </description>
  <isInput/>
  <isStdAIAA/>
</variableDef>
.
.
.
<variableDef name="dbfll" varID="DBFLL" units="deg" sign="TED"
  symbol="&#x3B4;bfl" >
  <description>
    Lower left body flap deflection, deg, positive trailing-edge-down (so
    deflections are
    always zero or positive).
  </description>
  <isInput/>
</variableDef>
```


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 227 of 343 |

DAVE-ML 2

- ❶ The name attribute is intended for humans to read, perhaps as the signal name in a wiring diagram. Note that "machNumber" is one of the standard AIAA simulation variable names.
- ❷ The varID attribute is intended for the processing application to read. This is an internal identifier that must be unique within this model.
- ❸ The optional isInput attribute indicates this variable should be treated as an input to the model for model hierarchy and linear model extraction (for example).
- ❹ The optional isStdAIAA sub-element indicates this signal is one of the predefined standard variables that most simulation facilities define in their equations of motion code. The name attribute should correspond to the standard AIAA parameter name from Annex A of [AIAA10] or subsequent standards document
- ❺ The mandatory units attribute describes the units of measure of the variable. See Section 6.5.6 (p. 56) below for a recommended list of units-of-measure abbreviations.
- ❻ The optional sign attribute describes the sign convention that applies to this variable. In this case, the lower-left body-flap is positive with trailing-edge-down deflection. See Section 6.5.5 (p. 56) below for a recommended list of sign abbreviations.
- ❼ The optional symbol attribute allows a UNICODE character string that might be used for this variable in a symbols listing.

Example 3. A simple local variable definition example

This DAVE-ML excerpt defines CLBFLLO which is the dependent variable (output) from a table lookup function (shown later in Example 11 (p. 41)). It is subsequently used in the calculation of the lower-left body flap lift coefficient (shown in Example 4 (p. 27)).

```

<!-- ***** -->
<!-- Local variables -->
<!-- ***** -->

<!-- PRELIMINARY BUILDUP EQUATIONS -->

<!-- LOWER LEFT BODY FLAP CONTRIBUTIONS -->

<!-- table output signal -->
<variableDef name="CLDbfl_0" varID="CLBFLLO" units="nd">
  <description>
    Output of CLBFLLO function; lift force contribution of
    lower left body flap deflection due to alpha^0 (constant
    term).
  </description>
</variableDef>

```

Since this signal is not flagged as an input, control, disturbance or output, this variable is an intermediate signal local to this model.


Example 4. A more complete variableDef example with a calculation element

In this example, the local variable CLBFL is defined as a calculated quantity, based on several other input or local variables including the CLBFLLO function output variable defined in the previous example (p. 27). Note the description element is used to describe the equation in Fortran-ish human-readable text. The calculation element describes this same equation in MathML-2 content markup syntax; this portion should be used by parsing applications to create either source code, documentation, or run-time calculation structures.

```

<!-- lower left body flap lift buildup -->
<variableDef name="CLDbfl" varID="CLBFL" units="nd">

```


| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 228 of 343 |

DAVE-ML 2

```


<description>
  Lift contribution of lower left body flap deflection
  CLdbfll = CLdbfll_0 + alpha*(CLdbfll_1 + alpha*(CLdbfll_2
    + alpha*CLdbfll_3)) ❶
</description>
<calculation> ❷
  <math xmlns="http://www.w3.org/1998/Math/MathML">
    <apply> ❸
      <plus/>
      <ci>CLBFL0</ci> ❹
      <apply>
        <times/>
        <ci>ALP</ci>
        <apply>
          <plus/>
          <ci>CLBFL1</ci>
          <apply>
            <times/>
            <ci>ALP</ci>
            <apply>
              <plus/>
              <ci>CLBFL2</ci>
              <apply> ❺
                <times/>
                <ci>ALP</ci>
                <ci>CLBFL3</ci>
              </apply> <!-- a*c3 --> ❻
            </apply> <!-- (c2 + a*c3) -->
          </apply> <!-- a*(c2 + a*c3) -->
        </apply> <!-- (c1 + a*(c2 + a*c3)) -->
      </apply> <!-- a*(c1 + a*(c2 + a*c3)) -->
    </apply> <!-- c0 + a*(c1 + a*(c2 + a*c3)) -->
  </math>
</calculation>
</variableDef>

```

- ❶ This Fortran-ish equation, located in the `description` element, is provided in this example for the benefit of human readers; it should not be parsed by the processing application.
- ❷ A `calculation` element always embeds a MathML-2 `math` element; note the definition of the MathML-2 namespace.
- ❸ Each `apply` tag pair surrounds a math operation (in this example, a plus operator) and the arguments to that operation (in this case, a variable CLBFL0 defined elsewhere is added to the results of the nested `apply` operation).
- ❹ The content identifier (`ci`) MathML-2 element gives the `varID` of the previously defined variables used in this equation; this variable represents the output of the CLBFL0 function found in Example 11 (p. 41) that is captured in the CLBFL0 variable defined in Example 3 (p. 27). The other `ci` elements are not defined in this manual but are defined in the full model.
- ❺ Inner-most `apply` multiplies variables ALP and CLBFL3.
- ❻ The comments here are useful for humans to understand how the equation is being built up; the processing application ignores all comments.

Example 5. Another example of an output variable based on a `calculation` element

This excerpt is an example of how an output variable (CL) might be defined from previously calculated local variables (in this case, CL0, CLBFL, etc.).

| | | | |
|---|--|--|------------------------------------|
|  | <div>NASA Engineering and Safety Center</div> <div>Technical Assessment Report</div> | <div>Document #:</div> <div>NESC-RP-09-00598</div> | <div>Version:</div> <div>1.0</div> |
| <div>Title:</div> <div>Flight Simulation Model Exchange</div> | <div>Page #:</div> <div>229 of 343</div> | | |

DAVE-ML 2

```

<!-- ===== -->
<!-- Output variables -->
<!-- ===== -->

<variableDef name="CL" varID="CL" units="nd" sign="+UP" symbol="CL">
  <description>
    Coefficient of lift
    CL = CL0 + CLBFUL + CLBFUL + CLBFL + CLBFLR +
          CLWFL + CLWFR + CLRU + CLGE + CLLG
  </description>
  <calculation>
    <math>
      <apply> ❶
        <plus/>
        <ci>CL0</ci>
        <ci>CLBFUL</ci>
        <ci>CLBFUL</ci>
        <ci>CLBFL</ci> ❷
        <ci>CLBFLR</ci>
        <ci>CLWFL</ci>
        <ci>CLWFR</ci>
        <ci>CLRU</ci>
        <ci>CLGE</ci>
        <ci>CLLG</ci>
      </apply>
    </math>
  </calculation>
  <isOutput/> ❸
</variableDef>

```

- ❶ Here apply simply sums the value of these variables, referenced by their varIDs.
- ❷ This ci element refers to the lower left body flap lift contribution calculated in the previous example (p. 27).
- ❸ The isOutput element signifies to the processing application that this variable should be made visible to models external to this DAVEfunc.

Example 6. An intermediate variable with a calculation element that uses a DAVE-ML function extension to the default MathML-2 function set


In this excerpt, we demonstrate a means to encode a math function, *atan2*, that is not available in the default MathML-2 function set. The *atan2* function is used often in C, C++, Java and other modeling languages and has been added to the DAVE-ML standard by use of the MathML-2 *csymbol* element, specifically provided to allow extension of MathML-2 for cases such as this.

```

<!-- ===== -->
<!-- ATAN2 example --> ❶
<!-- ===== -->

<variableDef name="Wind vector roll angle" varID="PHI" units="rad">
  <description>
    This encodes the equation PHI = atan2( tan(BETA), sin(ALPHA) ) where atan2
    is the two-argument arc tangent function from the ANSI C standard math
    library.
  </description>
  <calculation>
    <math>
      <apply>
        <csymbol definitionURL="http://daveml.org/function_spaces.html#atan2"
          encoding="text"> ❷
          atan2

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 230 of 343 |

DAVE-ML 2

```

</csymbol>
<apply>
  <tan/>
  <ci>BETA</ci> ❶
</apply>
<apply>
  <sin/>
  <ci>ALPHA</ci> ❷
</apply>
</apply>
</math>
</calculation>

</variableDef>

```

- ❶ This excerpt shows how to calculate wind roll angle, phi, from angle-of-attack and angle-of-sideslip; it comes from the Apollo aerodynamics data book [NAA64].
- ❷ The `csymbol` element is provided by MathML-2 as a means to extend the function set of MathML-2. An extension for `atan2` is the only function defined at present but others may be added to the set in the future. Note the specific URI that uniquely identifies this function; it is also the URL (web address) of the documentation of the interpretation of the `atan2` function.
- ❸ BETA is the `varID` of a previously defined variable.
- ❹ ALPHA is the `varID` of a previously defined variable.

6.2.3. The breakpoint set definition element

The breakpoint set definition element, `breakpointDef`, is used to define a list of comma- or white space-separated values that define the coordinate values along one axis of a gridded linear function value table. It contains a mandatory `bpID` attribute, an optional name and units-of-measure attributes, an optional text `description` element, and the comma- or white space-separated list of floating-point values in the `bpVals` element. This list must be monotonically increasing in value.

```

breakpointDef : bpID, [name, units]
  description? :
  bpVals :
    {character data of comma- or white space-separated breakpoints}


```

breakpointDef attributes:

| | |
|--------------------|--|
| <code>bpID</code> | An internal reference that is unique within the file. |
| <code>name</code> | A UNICODE name for the set (may be the same string as <code>bpID</code>). |
| <code>units</code> | The units-of-measure for the breakpoint values. See Section 6.5.6 (p. 56) below. |

breakpointDef sub-elements:

| | |
|--------------------------|--|
| <code>description</code> | An optional text description of the breakpoint set. |
| <code>bpVals</code> | A comma- or white space-separated, monotonically increasing list of floating-point values. |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 231 of 343 |

DAVE-ML 2

Example 7. Two `breakpointDef` examples in a DAVE-ML model excerpt

As an example, two breakpoint sets are defined which are used in the `function` element given below (Example 11 (p. 41)). Breakpoint sets `XMACH1_PTS` and `DBFL_PTS` contain values for Mach and lower body flap deflection, respectively, which are used to look up function values in several gridded function tables. One example is given below in Example 8 (p. 33).

```
<!-- ===== -->
<!-- ===== BREAKPOINT SETS ===== -->
<!-- ===== -->

<breakpointDef name="mach" bpID="XMACH1_PTS" units="nd"> ❶
  <description>
    Mach number breakpoints for all aero data tables
  </description>
  <bpVals>
    0.3, 0.6, 0.8, 0.9, 0.95, 1.1, 1.2, 1.6, 2.0, 2.5, 3.0, 3.5, 4.0 ❷
  </bpVals>
</breakpointDef>

<breakpointDef name="Lower body flap" bpID="DBFL_PTS" units="deg"> ❸
  <description>Lower body flap deflections breakpoints for tables</description>
  <bpVals>0., 15., 30., 45., 60.</bpVals>
</breakpointDef>
```

- ❶ This `breakpointDef` element describes a Mach breakpoint set uniquely identified as `XMACH1_PTS` with no associated units of measure.
- ❷ The breakpoint values are given as a comma- or white space-separated list and must be in monotonically increasing numerical order.
- ❸ This breakpoint set defines the breakpoints for lower body flap deflection.

6.2.4. The gridded table definition element


The `griddedTableDef` element defines a multi-dimensional table of values corresponding with the value of an arbitrary function at each intersection of a set of specified independent input values. The coordinates along each dimension are defined in separate `breakpointDef` elements that are referenced within this element by `bpRefs`, one for each dimension.

The data contained within the data table definition are a comma- or white space-separated set of floating-point values. This list of values represents a multi-dimensional array whose size is inferred from the length of each breakpoint vector. For example, a 2D table that is a function of an eight-element Mach breakpoint set and a ten-element angle-of-attack breakpoint set is expected to contain 80 (8 x 10) comma- or white space-separated values.

By convention, the `breakpointRefs` are listed in order such that the last breakpoint set varies most rapidly in the associated data table listing. See Section 6.5.1 (p. 55) below.

An optional `uncertainty` element may be provided that represents the statistical variation in the values presented. See Section 6.4 (p. 49) for more information about this element.

```
griddedTableDef : [name, gtID, units]
  description?
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 232 of 343 |

DAVE-ML 2

```

{description of table in character data}
EITHER
  provenanceRef? : provID
OR
  provenance? : [provID]
    author+ : name, org, [email]
    contactInfo* : [contactInfoType, contactLocation]
      {text describing contact information}
    creationDate : date {in YYYY-MM-DD format}
    documentRef* : [docID,] refID
    modificationRef* : modID
    description?
  breakpointRefs :
    bpRef+ : bpID
  uncertainty? : effect
    (normalPDF : numSigmas | uniformPDF)
  dataTable
    {character data of comma- or white space-separated table values}


```

griddedTableDef attributes:

| | |
|-------|---|
| gtID | An internal reference that is unique within the file. |
| name | A UNICODE name for the table (may be the same string as gtID). |
| units | The units-of-measure of the table's output signal. See Section 6.5.6 (p. 56) below. |

griddedTableDef sub-elements:

| | |
|----------------|---|
| description | The optional description element allows the author to describe the data contained within this griddedTable. |
| provenance | The optional provenance element allows the author to describe the source and history of the data within this griddedTable. Alternatively, a provenanceRef reference can be made to a previously defined provenance. |
| breakpointRefs | The mandatory breakpointRefs element contains separate bpRef elements, each pointing to a separately defined breakpointDef. Thus, the independent coordinates associated with this function table are defined elsewhere and only a reference is given here. The order of appearance of the bpRefs is important; see the text above. |
| uncertainty | This optional element, if present, describes the uncertainty of this parameter. See Section 6.4 (p. 49) for more information about this element. |
| dataTable | The numeric values of the function at the function vertices specified by the breakpoint sets are contained within this element, in a single comma- or white space-separated |

| | | | |
|---|--|--|------------------------|
|  | <h1>NASA Engineering and Safety Center</h1> <h2>Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h1>Flight Simulation Model Exchange</h1> | | | Page #: 233 of 343 |

DAVE-ML 2

list, representing an unraveled multi-dimensional table. Parsing this list and storing it in the appropriate array representation is up to the implementer. By convention, the last breakpoint value increases most rapidly.

Example 8. An excerpt showing an example of a `griddedTableDef` element

This nonlinear function table is used by a subsequent function in Example 11 (p. 41) to specify an output value based on two input values: body flap deflection and Mach number. This table is defined outside of a function element because this particular function table is used by two functions: one for the left-lower body flap and one for the lower-right body flap; thus, their actual independent (input) variable values might be different.


```

<!-- ===== --> ❶
<!-- Lower Body Flap Tables (definitions) -->
<!-- ===== -->

<griddedTableDef name="CLBFL0" gtID="CLBFL0_table"> ❷
  <description> ❸
    Lower body flap contribution to lift coefficient,
    polynomial constant term
  </description>
  <provenance> ❹
    <author name="Bruce Jackson" org="NASA Langley Research Center"
    email="e.b.jackson@larc.nasa.gov"/>
    <creationDate date="2003-01-31"/>
    <documentRef docID="REF01"/>
  </provenance>
  <breakpointRefs> ❺
    <bpRef bpID="DBFL PTS"/>
    <bpRef bpID="XMACH1 PTS"/>
  </breakpointRefs>
  <dataTable> <!-- last breakpoint (XMACH) changes most rapidly --> ❻
<!-- CLBFL0 POINTS -->
<!-- DBFL = 0.0 -->
0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
<!-- DBFL = 15.0 --> ❼
-0.86429E-02 , -0.10256E-01 , -0.11189E-01 , -0.12121E-01 , -0.13520E-01 ,
-0.86299E-02 , -0.53679E-02 , 0.76757E-02 , 0.11300E-01 , 0.62992E-02 ,
0.51902E-02 , 0.38813E-02 , 0.37366E-02 ,
<!-- DBFL = 30.0 -->
0.22251E-01 , 0.26405E-01 , 0.28805E-01 , 0.31206E-01 , 0.34806E-01 ,
0.31321E-01 , 0.28996E-01 , 0.19698E-01 , 0.18808E-01 , 0.12755E-01 ,
0.10804E-01 , 0.98493E-02 , 0.83719E-02 ,
<!-- DBFL = 45.0 -->
.
. {other points in table}
.
</dataTable>
</griddedTableDef>

```

- ❶ Comments are good practice for human readers
- ❷ name is used for documentation purposes; gtID is intended for automatic wiring (autocode) tools.
- ❸ Descriptions make for good practice whenever possible. Here we explain the contents of the function represented by the data points.

| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h1 style="text-align: center;">Flight Simulation Model Exchange</h1> | | Page #: 234 of 343 |

DAVE-ML 2

- ❶ provenance is the story of the origin of the data.
- ❷ These bpRefs are in the same order as the table is wrapped (see text above) and must be reflected in the referencing function in the same order. In this excerpt, the referencing function must list the independentVarRefs such that the signal that represents delta body flap (DBFL) must precede the reference to the signal that represents Mach number (XMACH).
- ❸ The points listed within the dataTable element are given as if the last bpRef varies most rapidly. See the discussion above.
- ❹ Embedded comments are a good practice.

6.2.5. The ungridded table definition element

The `ungriddedTableDef` element defines a set of non-orthogonal data points, along with their independent values (coordinates), corresponding with the dependent value of an arbitrary function.

A 'non-orthogonal' data set, as opposed to a gridded or 'orthogonal' data set, means that the independent values are not laid out in an orthogonal grid. This form must be used if the dependent coordinates in any table dimension cannot be expressed by a single monotonically increasing vector.

See the excerpts below for two instances of ungridded data.

An optional `uncertainty` element may be provided that represents the statistical variation in the values presented. See the section on Statistics below for more information about this element.

```


ungriddedTableDef : [utID, name, units]
  description? :
    {description character data}
  EITHER
    provenanceRef? : provID
  OR
    provenance? : [provID]
      author+ : name, org, [email]
      contactInfo* : [contactInfoType, contactLocation]
        {text describing contact information}
      creationDate : date {in YYYY-MM-DD format}
      documentRef* : [docID,] refID
      modificationRef* : modID
      description?
    uncertainty? : effect
      (normalPDF : numSigmas) | (uniformPDF : bounds+)
    dataPoint+ :
      {coordinate/value sets as character data}

```

ungriddedTableDef attributes:

| | |
|--------------------|--|
| <code>utID</code> | An internal reference that is unique within the file |
| <code>name</code> | An optional UNICODE name for the table (may be the same string as <code>utID</code>). |
| <code>units</code> | Optional units-of-measure for the table's output signal. |

ungriddedTableDef sub-elements:

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 235 of 343 |

DAVE-ML 2

| | |
|-------------|---|
| description | The optional description element allows the author to describe the data contained within this ungriddedTable. |
| provenance | The optional provenance element allows the author to describe the source and history of the data within this ungriddedTable. Alternatively, a provenanceRef reference can be made to a previously defined provenance. |
| uncertainty | This optional element, if present, describes the uncertainty of this parameter. See the section on Statistics below for more information about this element. |
| dataPoint | One or more sets of coordinate and output numeric values of the function at various locations within its input space. This element includes one coordinate for each function input variable. Parsing this information into a usable interpolative function is up to the implementer. By convention, the coordinates are listed in the same order that they appear in the parent function. |


Example 9. An excerpt showing an `ungriddedTableDef` element, encoding the data depicted in Figure 2 (p. 36).

This 2D function table is an example provided by Dr. Peter Grant of the University of Toronto. Such a table definition would be used in a subsequent `function` to describe how an output variable would be defined based on two independent input variables. The function table does not indicate which input and output variables are represented; this information is supplied by the `function` element later so that a single function table can be reused by multiple functions.

```
<ungriddedTableDef name="CLBASIC as function of flap angle and angle-of-
  attack" utID="CLBAlfaFlap_Table" units="nd">
  <description>
    CL basic as a function of flap angle and angle-of-attack. Note the alpha
    used in this table is with respect to the wing design plane (in degrees).
    Flap is in degrees as well.
  </description>

  <provenance>
    <author name="Peter Grant" org="UTIAS"/> ❶
    <creationDate date="2006-11-01"/>
    <documentRef refID="PRG1" />
  </provenance>

  <!--For ungridded tables you provide a list of dataPoints--> ❷
    <dataPoint> 1.0 -5.00 -0.44 <!-- flap, alfawdp, CLB--></dataPoint> ❸
    <dataPoint> 1.0 10.00 0.95 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 1.0 12.00 1.12 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 1.0 14.00 1.26 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 1.0 15.00 1.32 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 1.0 17.00 1.41 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 5.0 -5.00 -0.55 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 5.0 0.00 -0.03 <!-- flap, alfawdp, CLB--></dataPoint>
    <dataPoint> 5.0 5.00 0.50 <!-- flap, alfawdp, CLB--></dataPoint>
```

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 236 of 343 |

DAVE-ML 2

```

<dataPoint> 5.0 10.00 1.02 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 5.0 12.00 1.23 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 5.0 14.00 1.44 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 5.0 16.00 1.63 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 5.0 17.00 1.70 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 5.0 18.00 1.75 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint modID='A'> 10.0 -5.00 -0.40 <!-- flap, alfawdp, CLB--></
dataPoint> ❹
<dataPoint> 10.0 14.00 1.57 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 10.0 15.00 1.66 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 10.0 16.00 1.75 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 10.0 17.00 1.80 <!-- flap, alfawdp, CLB--></dataPoint>
<dataPoint> 10.0 18.00 1.84 <!-- flap, alfawdp, CLB--></dataPoint>

</ungriddedTableDef>

```

- ❶ Example courtesy of Dr. Peter Grant, U. Toronto
- ❷ Comments are a good idea for human readers
- ❸ For a 2D table such as this one, data points give two columns of independent breakpoint values and a third column of function values at those breakpoints.
- ❹ The modID attribute implies this point was edited during modification 'A' of this model, as described in the file header information.

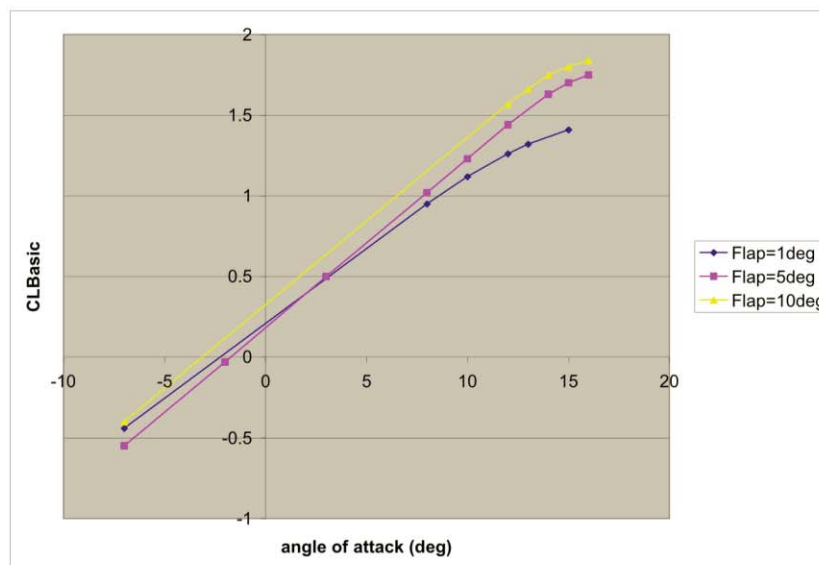



Figure 2. The 2D lift function given in Example 9 (p. 35)

Example 10. An excerpt from a sample aerodynamics model giving an example of a 3D ungriddedTableDef element, encoding the data shown in Figure 3 (p. 38).

In this example, the dependent coordinates all vary in each dimension.

| | | | |
|---|--|--|------------------------|
|  | <h1>NASA Engineering and Safety Center</h1> <h2>Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h1>Flight Simulation Model Exchange</h1> | | | Page #: 237 of 343 |

DAVE-ML 2


```

<!-------> ❶
<!-- Three-D Table Definition Example -->
<!------->

<ungriddedTableDef name="yawMomentCoefficientTable1" units="nd"
utID="yawMomentCoefficientTable1">
  <!-- alpha, beta, delta: yawMomentCoeff --> ❷
  <dataPoint> -1.8330592 -5.3490387 -4.7258599 -0.00350641</dataPoint>
  <dataPoint> -1.9302179 -4.9698462 0.2798654 -0.0120538</dataPoint>
  <dataPoint> -2.1213095 -5.0383145 5.2146443 -0.0207089</dataPoint>
  <dataPoint> 0.2522004 -4.9587161 -5.2312860 -0.000882368</dataPoint>
  <dataPoint> 0.3368831 -5.0797159 -0.3370540 -0.0111846</dataPoint>
  <dataPoint> 0.2987289 -4.9691198 5.2868938 -0.0208758</dataPoint>
  <dataPoint> 1.8858257 -5.2077654 -4.7313074 -0.00219842</dataPoint>
  <dataPoint> 1.8031083 -4.7072954 0.0541231 -0.0111726</dataPoint>
  <dataPoint> 1.7773659 -5.0317988 5.1507477 -0.0208074</dataPoint>
  <dataPoint> 3.8104785 -5.2982162 -4.7152852 -0.00225906</dataPoint>
  <dataPoint> 4.2631596 -5.1695257 -0.1343410 -0.0116563</dataPoint>
  <dataPoint> 4.0470946 -5.2541017 5.0686926 -0.0215506</dataPoint>
  <dataPoint> -1.8882611 0.2422452 -5.1959304 0.0113462</dataPoint>
  <dataPoint> -2.1796091 0.0542085 0.2454711 -0.000253915</dataPoint>
  <dataPoint> -2.2699103 -0.3146657 4.8638859 -0.00875431</dataPoint>
  <dataPoint> 0.0148579 0.1095599 -4.9639500 0.0105144</dataPoint>
  <dataPoint> -0.1214591 -0.0047960 0.2788827 -0.000487753</dataPoint>
  <dataPoint> 0.0610233 0.2029588 5.0831767 -0.00816086</dataPoint>
  <dataPoint> 1.7593356 -0.0149007 -5.0494446 0.0106762</dataPoint>
  <dataPoint> 1.9717048 -0.0870861 0.0763833 -0.000332616</dataPoint>
  <dataPoint> 2.0228263 -0.2962294 5.1777078 -0.0093807</dataPoint>
  <dataPoint> 4.0567507 -0.2948622 -5.1002243 0.010196</dataPoint>
  <dataPoint> 3.6534822 0.2163747 0.1369900 0.000312733</dataPoint>
  <dataPoint> 3.6848003 0.0884533 4.8214805 -0.00809437</dataPoint>
  <dataPoint> -2.3347682 5.2288720 -4.7193014 0.02453</dataPoint>
  <dataPoint> -2.3060350 4.9652745 0.2324610 0.0133447</dataPoint>
  <dataPoint> -1.8675176 5.0754646 5.1169942 0.00556052</dataPoint>
  <dataPoint> 0.0004379 5.1220145 -5.2734993 0.0250468</dataPoint>
  <dataPoint> -0.1977035 4.7462188 0.0664495 0.0124083</dataPoint>
  <dataPoint> -0.1467742 5.0470092 5.1806131 0.00475277</dataPoint>
  <dataPoint> 1.6599338 4.9352809 -5.1210532 0.0242646</dataPoint>
  <dataPoint> 2.2719825 4.8865093 0.0315210 0.0125658</dataPoint>
  <dataPoint> 2.0406858 5.3253471 5.2880688 0.00491779</dataPoint>
  <dataPoint> 4.0179983 5.0826426 -4.9597629 0.0243518</dataPoint>
  <dataPoint> 4.2863811 4.8806558 -0.2877697 0.0128886</dataPoint>
  <dataPoint> 3.9289361 5.2246849 4.9758705 0.00471241</dataPoint>
  <dataPoint> -2.2809763 9.9844584 -4.8800790 0.0386951</dataPoint>
  <dataPoint> -2.0733070 9.9204337 0.0241722 0.027546</dataPoint>
  <dataPoint> -1.7624546 9.9153493 5.1985794 0.0188357</dataPoint>
  <dataPoint> 0.2279962 9.8962508 -4.7811258 0.0375762</dataPoint>
  <dataPoint> -0.2800363 10.3004593 0.1413907 0.028144</dataPoint>
  <dataPoint> 0.0828562 9.9008011 5.2962722 0.0179398</dataPoint>
  <dataPoint> 1.8262230 10.0939436 -4.6710211 0.037712</dataPoint>
  <dataPoint> 1.7762123 10.1556398 -0.1307093 0.0278079</dataPoint>
  <dataPoint> 2.2258599 9.8009720 4.6721747 0.018244</dataPoint>
  <dataPoint> 3.7892651 9.8017197 -4.8026383 0.0368199</dataPoint>
  <dataPoint> 4.0150716 9.6815531 -0.0630955 0.0252014</dataPoint>
  <dataPoint> 4.1677953 9.8754433 5.1776223 0.0164312</dataPoint>
</ungriddedTableDef>

```

- ❶ Example courtesy of Mr. Geoff Brian, DSTO
- ❷ In this example, columns are labeled with an XML comment for human readers. Actual association of each input (alpha, beta and delta) and the single output (yawing moment) to the respective input and output signals is mechanized in any subsequent function definition(s).

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 238 of 343 |

DAVE-ML 2

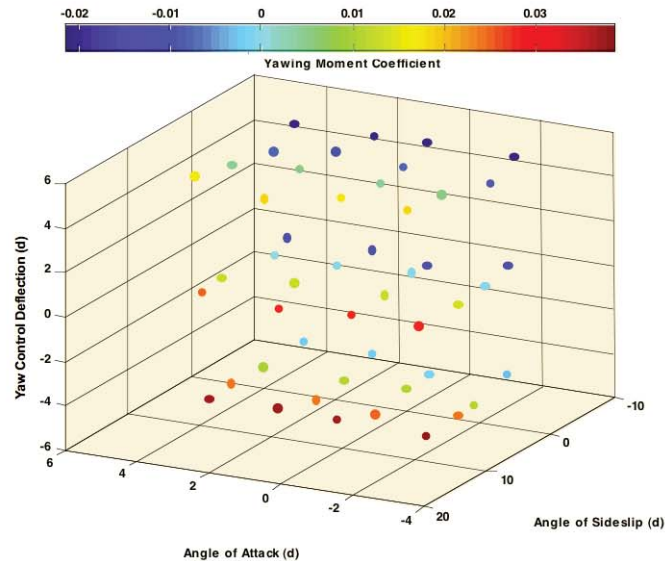


Figure 3. The 3D function given in the previous example


6.2.6. The function definition element

The function element connects breakpoint sets (for gridded tables), independent variables, and data tables (gridded or ungridded) to their respective output variable.

```

function : name
  description? :
    {text description of the function}
  EITHER
    provenanceRef? : provID
  OR
    provenance? : [provID]
    author+ : name, org, [email]
    contactInfo* : [contactInfoType, contactLocation]
    {text describing contact information}
    creationDate : date {in YYYY-MM-DD format}
    documentRef* : [docID,] refID
    modificationRef* : modID
    description?
  EITHER
    (
      independentVarPts+ : varID, [name, units, sign, extrapolate, interpolate]
      {input values as character data}
      dependentVarPts : varID, [name, units, sign]
      {output values as character data}
    )
  OR
    (

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 239 of 343 |

DAVE-ML 2

```

independentVarRef+ : varID, [min, max, extrapolate, interpolate]
dependentVarRef : varID
functionDefn : [name]
CHOICE OF
{
  griddedTableRef : gtID
OR
  griddedTableDef : [name, gtID, units]
  description?
    {text description of table}
  (provenance | provenanceRef)? {as described earlier}
  breakpointRefs
    bpRef+ : bpID
  uncertainty? : effect
    (normalPDF : numSigmas) | (uniformPDF : bounds+)
  dataTable
    {gridded data table as character data}
OR
  ungriddedTableRef : utID
OR
  ungriddedTableDef : [name, utID, units]
  description?
    {text description of table}
  (provenance | provenanceRef)? {as described earlier}
  uncertainty? : effect
    (normalPDF : numSigmas) | (uniformPDF : bounds+)
  dataPoint+
    {coordinate/value sets as character data}
}
)

```

function attributes:


name A UNICODE name for the function.

function sub-elements:

description The optional description element allows the author to describe the data contained within this function.


provenance The optional provenance element allows the author to describe the source and history of the data within this function. Alternatively, a provenanceRef reference can be made to a previously defined provenance.

independentVarPts If the author chooses, she can express a linearly interpolated functions by specifying the independent (breakpoint) value sets as one or more independentVarPts which are comma- or white space-separated, monotonically increasing floating-point coordinate values corresponding to the dependentVarPts. In the case of multiple dimensions, more than one independentVarPts must be specified, one for each dimension. The mandatory varID attribute is used to connect each independentVarPts set with an input variable.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 240 of 343 |

DAVE-ML 2

| | |
|--------------------------------|--|
| | <p>An optional <code>interpolate</code> attribute specifies the preference for using linear, quadratic, or cubic relaxed splines for calculating dependent values when the independent arguments are in between specified values. When not specified, the expectation would be to use a linear spline interpolation between points. The performance of interpolation of various orders is left up to the processing application. See Section 6.3 (p. 46).</p> |
| <code>dependentVarPts</code> | <p>This element goes along with the previous element to specify a function table. Only one <code>dependentVarPts</code> may be specified. If the function is multi-dimensional, the convention is the last breakpoint dimension changes most rapidly in this comma- or white space-separated list of floating-point output values. The mandatory <code>varID</code> attribute is used to connect this table's output to an output variable.</p> |
| <code>independentVarRef</code> | <p>One or more of these elements refers to separately defined <code>variableDefs</code>. The order of specification is important and must match the order in which breakpoint sets are specified or the order of coordinates in ungridded table coordinate/value sets.</p> <p>An optional <code>interpolate</code> attribute specifies the preference for using discrete, linear, quadratic, or cubic splines for calculating dependent values when the independent arguments are in between specified values. When not specified, the default expectation would be a linear spline interpolation between points. The performance of interpolation of various orders is left up to the implementer. See Section 6.3 (p. 46).</p> |
| <code>dependentVarRef</code> | <p>A single <code>dependentVarRef</code> must be specified to connect the output of this function to a particular <code>variableDef</code>.</p> |
| <code>functionDefn</code> | <p>This element identifies either a separately specified data table definition or specifies a private table, either gridded or ungridded.</p> |
| <code>griddedTableRef</code> | <p>If not defining a simple function table, the author may use this element to point to a separately specified <code>griddedTableDef</code> element.</p> |
| <code>ungriddedTableRef</code> | <p>If not using a simple function table, the author may use this element to point to separately specified <code>ungriddedTableDef</code> element.</p> |

| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h1 style="text-align: center;">Flight Simulation Model Exchange</h1> | | Page #: 241 of 343 |

DAVE-ML 2

Example 11. An excerpt giving the example of a function which refers to a previously defined `griddedTableDef`

This example ties the input variables DBFLL and XMACH into output variable CLBFLLO through a function called CLBFLLO_fn, which is represented by the linear interpolation of the gridded table previously defined by the CLBFLLO_table griddedTableDef (see the griddedTableDef example above).

```

<!-- ===== -->
<!-- Lower left body flap functions -->
<!-- ===== -->

<function name="CLBFLLO">
  <description>
    Lower left body flap lookup function for lift, polynomial constant term.
  </description>
  <independentVarRef varID="DBFLL" min="0.0" max="60." extrapolate="neither"/> ❶
  <independentVarRef varID="XMACH" min="0.3" max="4.0" extrapolate="neither"/>
  <dependentVarRef varID="CLBFLLO"/> ❷
  <functionDefn name="CLBFLLO_fn">
    <griddedTableRef gtID="CLBFLLO_table"/> ❸
  </functionDefn>
</function>

```

- ❶ The independent variables must be given in the order of least-rapidly changing to most-rapidly changing values in the previously defined function table. The processing application needs to pay attention to the `extrapolate` attribute, which specifies how to treat a variable whose value exceeds the stated limits on input. See Section 6.3 (p. 46).
- ❷ The dependent variable (identified as CLBFLLO) is the output variable for this function. CLBFLLO must have been declared previously with a `variableDef` element.
- ❸ This is a reference to the previously declared `griddedTableDef`.

Example 12. A `function` with an internal table

In this example, the function CLRUD0 returns, in the variable CLRUD0, the value of function CLRUD0_fn represented by gridded CLRUD0_table. The inputs to the function are `abs_rud` and `XMACH` which are used to normalize breakpoint sets `DRUD_PTS` and `XMACH1_PTS` respectively. The input variables are limited between 0.0 to 30.0 and 0.3 to 4.0, respectively.

In this case, the use of the CLRUD0 string for both the function name attribute and as the `varID` for the dependent (output) variable reference does not interfere (although they are confusing); name is not in the XML namespace. The name attribute is only used for documentation (such as a label for a box representing this function).


```

<!-- ===== -->
<!-- Rudder functions -->
<!-- ===== -->

<!-- The rudder functions are only used once, so their table
    definitions are internal to the function definition.
--> ❶

<function name="CLRUD0"> ❷
  <description>

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 242 of 343 |

DAVE-ML 2

```

Rudder contribution to lift coefficient,
polynomial multiplier for constant term.
</description>
<provenance> ❸
  <author name="Bruce Jackson" org="NASA Langley Research Center"
email="e.b.jackson@larc.nasa.gov"/>
  <creationDate date="2003-01-31"/>
  <documentRef docID="REF01"/>
</provenance>
<independentVarRef varID="abs_rud" min="0.0" max="30." extrapolate="neither"/>
<independentVarRef varID="XMACH" min="0.3" max="4.0" extrapolate="neither"/>
<dependentVarRef varID="CLRUD0"/> ❹

<functionDefn name="CLRUD0_fn">
  <griddedTableDef name="CLRUD0_table"> ❺
    <breakpointRefs>
      <bpRef bpID="DRUD_PTS"/>
      <bpRef bpID="XMACH1_PTS"/>
    </breakpointRefs>
    <dataTable> <!-- last breakpoint changes most rapidly -->
<!-- CLRUD0 POINTS -->
<!-- RUD = 0.0 -->
0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
<!-- RUD = 15.0 -->
-0.13646E-01 , 0.26486E-01 , 0.16977E-01 , -0.16891E-01 , 0.10682E-01 ,
0.75071E-02 , 0.53891E-02 , -0.30802E-02 , -0.59013E-02 , -0.95733E-02 ,
0.00000E+00 , 0.00000E+00 , 0.00000E+00 ,
<!-- RUD = 30.0 -->
-0.12709E-02 , 0.52971E-01 , 0.33953E-01 , -0.33782E-01 , 0.21364E-01 ,
0.15014E-01 , 0.10778E-01 , -0.61604E-02 , -0.11803E-01 , -0.19147E-01 ,
0.00000E+00 , 0.00000E+00 , 0.00000E+00
    </dataTable>
  </griddedTableDef>
</functionDefn>
</function>

```

- ❶ This comment helps humans understand the reason for an embedded table.
- ❷ The name attribute is used for documentation purposes, not for internal variable linkage.
- ❸ The provenance element is required by the AIAA standard [AIAA10].
- ❹ The varID attribute is used to link the output of this function with a previously defined variable as given in Example 3 (p. 27).
- ❺ This example has an embedded gridded table.


Example 13. A simple 1D function

At the other end of the spectrum, a simple 1D nonlinear function can be defined with no reuse, as shown below; however, multiple-dimension functions are supported by adding additional independentVarPts definitions.

```

<function name="CL">
  <independentVarPts varID="alpdeg"> ❶
    -4.0, 0., 4.0, 8.0, 12.0, 16.0
  </independentVarPts>
  <dependentVarPts varID="cl"> ❷
    0.0, 0.2, 0.4, 0.8, 1.0, 1.2
  </dependentVarPts>
</function>

```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 243 of 343 |

DAVE-ML 2

- ❶ Breakpoints in angle-of-attack are listed here.
- ❷ Values of c1 are given, corresponding to the angle-of-attack breakpoints given previously.

6.2.7. The checkData element

The `checkData` element contains one or more input/output vector pairs (and optionally a dump of internal values) for the encoded model to assist in verification and debugging of the implementation.

```

checkData
  staticShot+ : name, [refID]
    description?
      {text description of the static test case}
      (provenance | provenanceRef)? {as defined previously}
    checkInputs
      signal+
        signalName
        signalUnits
        signalValue
    internalValues?
      signal+
        varID
        signalValue
    checkOutputs
      signal+
        signalName
        signalUnits
        signalValue
    tol

```

checkData sub-elements:

staticShot One or more check-case data sets, each of which contain mandatory sub-elements `checkInputs` and `checkOutputs` vectors (with required match tolerances), and optional `provenance`, `provenanceRef`, `description` and `internalValues` sub-elements.


Example 14. Check-case data set excerpt

A DAVE-ML file excerpt specifying a check-case data set example for a simple model

```

<checkData>
  <staticShot name="Nominal" refID="NOTE1"> ❶
    <description>An example static check of a simple DAVE-ML model</description>
    <checkInputs> ❷
      <signal> ❸
        <signalName>trueAirspeed</signalName>
        <signalUnits>f_s</signalUnits>
        <signalValue> 300.000</signalValue>
      </signal>
      <signal>
        <signalName>angleOfAttack</signalName>
        <signalUnits>deg</signalUnits>
        <signalValue> 5.000</signalValue>

```

| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h2 style="text-align: center;">Flight Simulation Model Exchange</h2> | | | Page #: 244 of 343 |

DAVE-ML 2

```

</signal>
.
.   (similar input signals omitted)
.
<signal>
  <signalName>delta_elevator</signalName>
  <signalUnits>deg</signalUnits>
  <signalValue> 0.000</signalValue>
</signal>
</checkInputs>
<checkOutputs> ❶
  <signal> ❷
    <signalName>CX</signalName>
    <signalUnits>nd</signalUnits>
    <signalValue>-0.004000000000000</signalValue>
    <tol>0.000001</tol>
  </signal>
.
.   (similar output signals omitted)
.
</checkOutputs>
</staticShot>
<staticShot name="Positive pitch rate"> ❸
  <checkInputs>
    .
    .   (similar input and output signal information omitted)
    .
  </checkOutputs>
</staticShot>
<staticShot name="Positive elevator">
  <checkInputs>
    .
    .   (similar input and output signal information omitted)
    .
  </checkOutputs>
</staticShot>
</checkData>

```

- ❶ This first check-case refers to a note given in the file header; this is useful to document the source of the check-case values.
- ❷ The `checkInputs` element defines the input variable values, by variable name, as well as units (so they can be verified).
- ❸ Multiple `signal` elements are usually given; taken together, these scalar signals represent the check-case input "vector."
- ❹ The `checkOutputs` element defines output variable values that should result from the specified input values.
- ❺ Note the included tolerance value, indicating the absolute value tolerance within which the output values must match the check-case data values.
- ❻ Multiple check-cases may be specified; this one differs from the previous check-case due to an increase in the pitching-rate input.


Example 15. A second `checkData` example with internal values

This example shows another check-case; this one includes intermediate values as an aide to debugging a new implementation.

```

<checkData>
  <{ provenance | provenanceRef }?>
  <staticShot name="Skewed inputs">

```

| | | | |
|---|--|--|------------------------|
|  | <h1>NASA Engineering and Safety Center</h1> <h2>Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: <h1>Flight Simulation Model Exchange</h1> | | | Page #: 245 of 343 |


DAVE-ML 2

```

<description>
  Another example static check; this one includes all the internal, intermediate
  calculations
  to assist in debugging the implementation.
</description>
<checkInputs>
  <signal>
    <signalName>trueAirspeed</signalName>
    <signalUnits>f_s</signalUnits>\
    <signalValue> 300.000</signalValue>
  </signal>
  <signal>
    <signalName>angleOfAttack</signalName>
    <signalUnits>deg</signalUnits>
    <signalValue> 16.200</signalValue>
  </signal>
  .
  .   (similar input values omitted)
  .
  <signal>
    <signalName>bodyPositionOfCmWrtMrc</signalName>
    <signalUnits>fracMAC</signalUnits>
    <signalValue> 0.123</signalValue>
  </signal>
</checkInputs>
<internalValues> ❶
  <signal>
    <varID>vt</varID>
    <signalValue>300.0</signalValue>
  </signal>
  <signal>
    <varID>alpha</varID>
    <signalValue>16.2</signalValue>
  </signal>
  .
  .   (similar internal values omitted)
  .
</internalValues>
<checkOutputs>
  <signal>
    <signalName>aeroBodyForceCoefficient_X</signalName>
    <signalValue> 0.04794994533333</signalValue>
    <signalUnits>nd</signalUnits>
    <tol>0.000001</tol>
  </signal>
  <signal>
    <signalName>aeroBodyForceCoefficient_Z</signalName>
    <signalValue>-0.72934852554344</signalValue>
    <signalUnits>nd</signalUnits>
    <tol>0.000001</tol>
  </signal>
  <signal>
    <signalName>aeroBodyMomentCoefficient_Pitch</signalName>
    <signalValue>-0.10638585796503</signalValue>
    <signalUnits>nd</signalUnits>
    <tol>0.000001</tol>
  </signal>
</checkOutputs>
</staticShot>
</checkData>

```

- ❶ The internalValues element, if present, usually is a list of all model-defined internal variable values. This is normally not required for a model exchange, but such information is very useful to aide in debugging the implementation by the recipient.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 246 of 343 |

DAVE-ML 2

6.3. Function interpolation/extrapolation

It is possible to specify the method of interpolation to be used for nonlinear function tables by use of the `interpolate` attribute of the `independentVarPts` and `independentVarRef` elements. This attribute, combined with the `extrapolate` flag, provides several different ways of realizing the intermediate values of the function when not at one of the specified intersections of independent values.

Possible values for the `interpolate` attribute are:

| | |
|-------------------------------|---|
| <code>discrete</code> | Output uses value associated with nearest breakpoint |
| <code>floor</code> | Output uses value associated with next (numerically higher) breakpoint |
| <code>ceiling</code> | Output uses value associated with last (numerically lower) breakpoint |
| <code>linear</code> (default) | Output is linearly interpolated between breakpoints |
| <code>quadraticSpline</code> | Output follows a quadratic spline fit through values associated with two nearby breakpoints |
| <code>cubicSpline</code> | Output follows a cubic spline fit through values associated with three nearby breakpoints |


Possible values for the `extrapolate` attribute are:

| | |
|--------------------------------|---|
| <code>neither</code> (default) | Output is held constant at value associated with closest end of breakpoints if the input value is outside the limits of the associated breakpoint set |
| <code>min</code> | Output follows extrapolated values of function if the input is below the minimum breakpoint value |
| <code>max</code> | Output follows extrapolated values of function if the input is above maximum breakpoint value |
| <code>both</code> | Output follows extrapolated values of function if the input is outside the limits of the associated breakpoint set |

Implementation of the specific interpolation algorithm is left up to the implementer. One reference is the Wikipedia entry on interpolation [wiki01].

The following implementation notes are suggested:

- An infinite set of quadratic interpolations are possible; it is suggested to use the one that minimizes either the deviation from a linear interpolation or the slope error at any edge.
- For cubic interpolation, the natural cubic spline (which has a second derivative of zero at each end) is recommended when the `extrapolate` attribute is none. When the `extrapolate`

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 247 of 343 |

DAVE-ML 2

attribute is both, a clamped cubic spline that matches the extrapolated slope of the last two data points is suggested.


- For the discrete interpolation values (`discrete`, `ceiling`, or `floor`), the value of the `extrapolate` attribute is meaningless.

For discrete interpolation,

- `discrete` implies the change between output values occurs midway between independent breakpoint values, as shown in the top plot of Figure 4 (p. 48).
- `ceiling` means the output takes on the value of the next-higher dependent variable breakpoint as soon as each independent breakpoint value is passed (assuming the input value is increasing) as shown in the middle plot of Figure 4 (p. 48).
- `floor` means the output retains the value of the last dependent variable breakpoint until the next independent breakpoint value is reached (assuming the input value is increasing) as shown in the bottom plot of Figure 4 (p. 48).

The default value for `interpolate` is `linear`. The default value for `extrapolate` is `neither`.

Figures 4 (p. 48) and 5 (p. 49) below give nine different examples for a 1D table whose independent values are [1, 3, 4, 6, 7.5] with dependent values of [2, 6, 5, 7, 1.5].

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 248 of 343 |

DAVE-ML 2

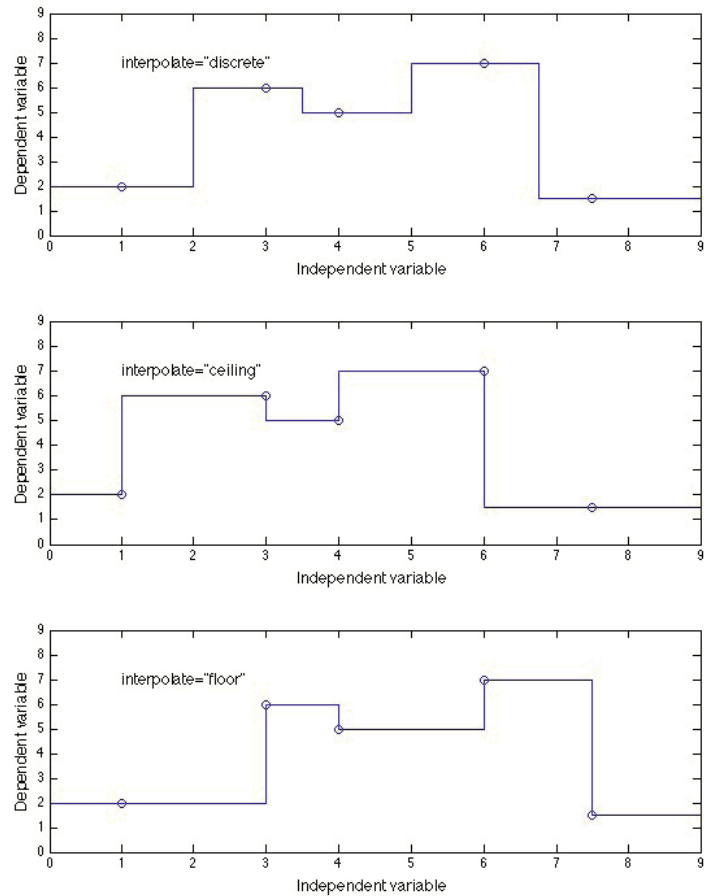



Figure 4. Example of the three discrete enumeration values of interpolate attribute of the independentVarPts and independentVarRef elements for a 1D function table.

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 249 of 343 |

DAVE-ML 2

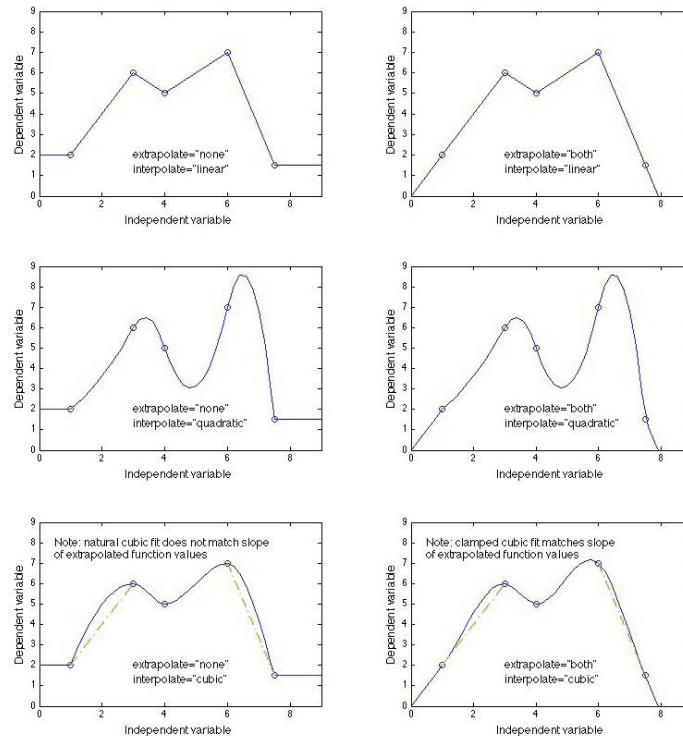



Figure 5. Examples of the three higher-order interpolation methods showing the effect of the `interpolate` attribute of the `independentVarPts` and `independentVarRef` elements for a 1D function table.

6.4. Statistical information encoding

Statistical measures of variation of certain parameters and functions can be embedded in a DAVE-ML model in several ways. This information is captured in an `uncertainty` element, which can be referenced by `variableDef`, `griddedTableDef` and `ungriddedTableDef` elements. For maximum modeling flexibility, it is possible to add uncertainty to the independent value arguments to a function or calculation, to the output of a function itself, as well as to any output signal. Applying uncertainty at more than one location in a calculation change is probably not a good practice, however.

Details on providing the random values for uncertainties is left to the implementer.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 250 of 343 |

DAVE-ML 2

Uncertainty in the value of a parameter or function is given in one of two ways, depending on the appropriate probability distribution function (PDF): as a Gaussian or normal distribution (bell curve) or as a uniform (evenly spread) distribution. One of these distributions is selected by including either a `normalPDF` or a `uniformPDF` element within the `uncertainty` element.

Linear correlation between the randomness of two or more variables or functions can be specified. Although the correlation between parameters does not have a dependency direction (i.e., the statistical uncertainty of one parameter is specified in terms of the other parameter, therefore the calculation order does not matter), correlation is customarily specified as a dependency of one random variable on the value of another random variable. `correlatesWith` identifies variables or functions whose uncertainty 'depends' on the current value of this variable or parameter; the `correlation` sub-element specifies the correlation coefficient and identifies the (previously calculated) random variable or function on which the correlation depends.

These correlation sub-elements only apply to normal (Gaussian) probability distribution functions.

Each of these distribution description elements contain additional information, as described below.

```

uncertainty : effect=['additive'|'multiplicative'|'percentage'|'absolute']
  EITHER
    normalPDF : numSigmas=['1'|'2'|'3']
      bounds { scalar value representing the one, two or three sigma bound };
      (correlatesWith* : varID |
        correlation* : varID, corrCoef )
    OR
    uniformPDF
      bounds { one or two scalar values for abs. or min/max bounds }


```

uncertainty attributes:

| | |
|---------------|--|
| effect | Indicates, by choice of four enumerated values, how the uncertainty is modeled: as an additive, multiplicative, or percentage variation from the nominal value, or a specific number (absolute). |
|---------------|--|

uncertainty sub-elements:

| | |
|-------------------|---|
| normalPDF | If present, the uncertainty in the parameter value has a probability distribution that is Gaussian (bell-shaped). A single parameter representing the additive (\pm some value), percentage (\pm some %) of variation from the nominal value in terms of 1, 2, 3, or more standard deviations (sigmas) is specified. Note: multiplicative and absolute bounds do not make much sense. |
| uniformPDF | If present, the uncertainty in the parameter or function value has a uniform likelihood of taking on any value between symmetric or asymmetric boundaries, which |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 251 of 343 |

DAVE-ML 2

are specified in terms of additive (either $\pm x$ or $+x/-y$), multiplicative, percentage, or absolute variations. If absolute, the specified range of values must bracket the nominal value. For this element, the `bounds` sub-element may contain one or two values, in which case the boundaries are symmetric or asymmetric.

Example 16. A variable with absolute uncertainty bounds

This example shows how to specify that a constant parameter can take on a specified range of values with uniform probability distribution. The nominal value of the minimum drag coefficient is specified to be 0.005, but when performing parametric variations, it is allowed to take on values between 0.001 and 0.010.


```
<DAVEfunc>
  <fileHeader>
    .
    .
  </fileHeader>
  <variableDef name="CD zero" varID="CD0" units="nd" initialValue="0.005"> ❶
    <description>
      Minimum coefficient of drag with an
      asymmetric uniform uncertainty band
    </description>
    <isOutput/>
    <uncertainty effect="absolute"> ❷
      <uniformPDF>
        <bounds>0.001</bounds>
        <bounds>0.010</bounds>
      </uniformPDF>
    </uncertainty>
  </variableDef>
</DAVEfunc>
```

- ❶ We declare the parameter `CD0` as having a nominal value of 0.005.
- ❷ When parametric variations are applied, the value of `CD0` can vary uniformly between 0.001 and 0.010.

Example 17. 10% uncertainty applied to output variable with a uniform distribution

This example shows how to specify that a variable has a 10% uniformly distributed uncertainty band. In this example, the output variable comes from a nonlinear 1D function and the uncertainty is applied to the output of the table.

```
<DAVEfunc>
  <fileHeader>
    .
    .
  </fileHeader>
  <variableDef name="angleOfAttack" varID="Alpha_deg" units="deg">
    <isStdAIAA/>
  </variableDef>
  <variableDef name="Cm_u" varID="Cm_u" units="nd">
    <description>
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 252 of 343 |

DAVE-ML 2

```

Coefficient of pitching moment with 10 percent
symmetric uniform uncertainty band
</description>
<isOutput/>
<uncertainty effect="percentage"> ❶
  <uniformPDF>
    <bounds>10.0</bounds>
  </uniformPDF>
</uncertainty>
</variableDef>
<breakpointDef bpID="ALP">
  <bpVals>0, 5, 10, 15, 20, 25, 30, 35</bpVals>
</breakpointDef>
<function name="Nominal Cm">
  <description>
    Nominal pitching moment values prior to application
    of uncertainty
  </description>
  <independentVarRef varID="Alpha_deg"/>
  <dependentVarRef varID="Cm_u"/>
  <functionDefn> ❷
    <griddedTableDef>
      <breakpointRefs>
        <bpRef bpID="ALP"/>
      </breakpointRefs>
      <dataTable>
5.2, 4.3, 3.1, 1.8, 0.3, 0.1, 0.0, -0.1
      </dataTable>
    </griddedTableDef>
  </functionDefn>
</function>
</DAVEfunc>

```

- ❶ We declare the output variable Cm_u as having the uncertainty of $\pm 10\%$ uniform distribution.
- ❷ This function gives the nominal values of Cm_u as a 1D function of angle-of-attack (alpha).


Example 18. Asymmetric additive uncertainty applied to output variable with uniform distribution

This example shows how to specify that a variable has an asymmetric, uniformly distributed, additive uncertainty band. In this example, the output variable comes from a nonlinear 1D function and the uncertainty is applied to the output of the table.

```

<DAVEfunc>
  <fileHeader>
    .
    .
    .
  </fileHeader>
  <variableDef name="angleOfAttack" varID="Alpha_deg" units="deg">
    <isStdAIAA/>
  </variableDef>
  <variableDef name="Cm_u" varID="Cm_u" units="nd">
    <description>
      Coefficient of pitching moment with an
      asymmetric uniform uncertainty band
    </description>
    <isOutput/>
    <uncertainty effect="additive"> ❶
      <uniformPDF>
        <bounds>-0.50</bounds>
        <bounds>0.00</bounds>
      </uniformPDF>
    </uncertainty>
  </variableDef>
</DAVEfunc>

```


| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 253 of 343 |

DAVE-ML 2

```

        </uniformPDF>
    </uncertainty>
</variableDef>
<breakpointDef bpID="ALP">
    <bpVals>0, 5, 10, 15, 20, 25, 30, 35</bpVals>
</breakpointDef>
<function name="Nominal Cm">
    <description>
        Nominal pitching moment values prior to application
        of uncertainty
    </description>
    <independentVarRef varID="Alpha_deg"/>
    <dependentVarRef varID="Cm_u"/> ②
    <functionDefn>
        <griddedTableDef>
            <breakpointRefs>
                <bpRef bpID="ALP"/>
            </breakpointRefs>
            <dataTable>
2.5.2, 4.3, 3.1, 1.8, 0.3, 0.1, 0.0, -0.1
            </dataTable>
        </griddedTableDef>
    </functionDefn>
</function>
</DAVEfunc>

```

- ① We declare the output variable Cm_u varies by as much as ± 0.5 to ± 0.0 about the nominal value. This delta value is in the same units as the nominal value (i.e. it is not a multiplier or percentage but an additive delta to the nominal value which comes from the 1D Cm_u function table description).
- ② This function gives the nominal values of Cm_u as a 1D function of angle-of-attack (α).


Example 19. A 1D point-by-point, Gaussian distribution function

In this example, a Gaussian (normal) distribution function is applied to *each* point in a 1D function table, with the 3-sigma value expressed as a multiplier of the nominal value.

```

<DAVEfunc>
    <fileHeader>
        .
        .
        .
    </fileHeader>
    <variableDef name="angleOfAttack" varID="Alpha_deg" units="deg">
        <isStdAIAA/>
    </variableDef>
    <variableDef name="Cm_u" varID="Cm_u" units="nd">
        <description>
            Coefficient of pitching moment with 10 percent
            symmetric uniform uncertainty band
        </description>
        <isOutput/>
    </variableDef>
    <breakpointDef bpID="ALP">
        <bpVals>0, 5, 10, 15, 20, 25, 30, 35</bpVals>
    </breakpointDef>
    <function name="Uncertain Cm">
        <independentVarRef varID="Alpha_deg"/>
        <dependentVarRef varID="Cm_u"/>
        <functionDefn>
            <griddedTableDef>
                <breakpointRefs>

```

| | | | |
|---|--|--|--------------------------|
|  | <h1 style="text-align: center;">NASA Engineering and Safety Center</h1> <h2 style="text-align: center;">Technical Assessment Report</h2> | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | <h1 style="text-align: center;">Flight Simulation Model Exchange</h1> | | Page #: 254 of 343 |

DAVE-ML 2

```

    <bpRef bpID="ALP"/>
  </breakpointRefs>
  <uncertainty effect="multiplicative"> ❶
    <normalPDF numSigmas="3"> ❷
      <bounds>
        <dataTable> ❸
          0.10, 0.08, 0.06, 0.05, 0.05, 0.06, 0.07, 0.12
        </dataTable>
      </bounds>
    </normalPDF>
  </uncertainty>
  <dataTable> ❹
    5.2, 4.3, 3.1, 1.8, 0.3, 0.1, 0.0, -0.1
  </dataTable>
</griddedTableDef>
</functionDefn>
</function>
</DAVEfunc>

```

- ❶ This declares the statistical uncertainty bounds of the C_{m_u} dependent variable will be expressed as a multiplication of the nominal value.
- ❷ This declares that the probability distribution is a normal distribution and the bounds represent 3-sigma (99.7%) confidence bounds.
- ❸ This table lists three-sigma bounds of each point of the C_{m_u} function as a table. The table must have the same dimensions and independent variable arguments as the nominal function; it is in effect an overlay to the nominal function table, but the values represent the bounds as multiples of the nominal function value.
- ❹ This table defines the nominal values of the function; these values will be used if the random variable associated with the uncertainty of this function is zero or undefined by the application.


Example 20. Two nonlinear functions with correlated uncertainty

In this example, uncertainty in pitching-moment coefficient varies in direct correlation with lift coefficient uncertainty.

```

<DAVEfunc>
  <fileHeader> . . . </fileHeader>
  <variableDef name="angleOfAttack" varID="Alpha_deg" units="deg">
    <isStdAIAA/>
  </variableDef>
  <variableDef name="CL_u" varID="CL_u" units="nd">
    <description> Coefficient of lift with a symmetric Gaussian uncertainty
      of 20%; correlates with  $C_m$  uncertainty. </description>
    <uncertainty effect="multiplicative"> ❶
      <normalPDF numSigmas="3">
        <bounds>0.20</bounds>
        <correlatesWith varID="Cm_u"/> ❷
      </normalPDF>
    </uncertainty>
  </variableDef>
  <variableDef name="Cm_u" varID="Cm_u" units="nd">
    <description> Coefficient of pitching moment with a symmetric Gaussian
      uncertainty
      distribution of 30%; correlates directly with lift uncertainty. </
    description>
    <isOutput/>
    <uncertainty effect="percentage"> ❸

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 255 of 343 |

DAVE-ML 2

```

        <normalPDF numSigmas="3">
          <bounds>30</bounds>
          <correlation varID="CL_u" corrCoef="1.0"/> ❹
        </normalPDF>
      </uncertainty>
    </variableDef>
    <breakpointDef bpID="ALP">
      <bpVals>0, 5, 10, 15, 20, 25, 30, 35</bpVals>
    </breakpointDef>
    <function name="Nominal CL">
      <description> Nominal lift coefficient values prior to uncertainty </
description>
      <independentVarRef varID="Alpha_deg"/>
      <dependentVarRef varID="CL_u"/>
      <functionDefn>
        <griddedTableDef>
          <breakpointRefs><bpRef bpID="ALP"/></breakpointRefs>
          <dataTable> 0.0, 0.1, 0.2, 0.3, 0.4, 0.45, 0.5, 0.45 </dataTable>
        </griddedTableDef>
      </functionDefn>
    </function>
    <function name="Nominal Cm">
      <description> Nominal pitching moment values prior to uncertainty </
description>
      <independentVarRef varID="Alpha_deg"/>
      <dependentVarRef varID="Cm_u"/>
      <functionDefn>
        <griddedTableDef>
          <breakpointRefs><bpRef bpID="ALP"/></breakpointRefs>
          <dataTable> 5.2, 4.3, 3.1, 1.8, 0.3, 0.1, 0.0, -0.1 </dataTable>
        </griddedTableDef>
      </functionDefn>
    </function>
  </DAVEfunc>

```


- ❶ Lift coefficient has a nominal value that varies with angle-of-attack according to a nonlinear 1D table (given in the "Nominal CL" table defined in this example). When performing parametric variations, CL_u can take on a multiplicative variation of up to 20% (3-sigma) with a Gaussian distribution.
- ❷ This element indicates that the variation of lift coefficient correlates directly with the variation in pitching moment coefficient.
- ❸ Pitching-moment coefficient has a nominal value that varies as a function of angle-of-attack, according to a nonlinear 1D table (given in the "Nominal Cm" table defined in this example). When performing parametric variations, Cm_u can take on a 30% variation (3-sigma) with a Gaussian distribution.
- ❹ This element indicates that the variation of pitching moment correlates directly with the variation in lift coefficient.

6.5. Additional DAVE-ML conventions

To facilitate the interpretation of DAVE-ML packages, the following conventions are proposed. Failure to follow any of these conventions should be noted prominently in the data files and any cover documentation.

6.5.1. Ordering of points

In listing data points in multi-dimensional table definitions, the sequence should be such that the last dimension changes most rapidly. In other words, a table that is a function of $f(a,b,c)$ should

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 256 of 343 |

DAVE-ML 2

list the value for $f(1,1,1)$, then $f(1,1,2)$, etc. This may be different than, say, a Fortran DATA, Matlab® script or C++ initialization statement; the responsibility for mapping the data in the correct sequence in the model realization is left up to the implementer.

Figure 6 (p. 56) below shows how a 3D table is represented as an unraveled list of points.

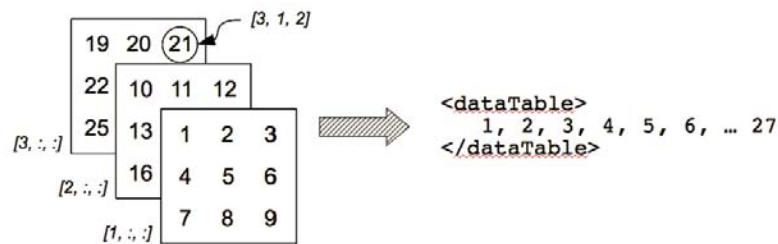


Figure 6. An unraveled list compared to the original 3D table

6.5.2. Locus of action of moments

It is recommended that all force and moments be considered to act around a defined reference point, given in aircraft coordinates. It is further recommended that all subsystem models (aerodynamic, propulsive, alighting gear) provide total forces and moments about this reference point and leave the transfer of moments to the center of mass to the equations of motion.

6.5.3. Decomposition of flight dynamics subsystems

It is recommended that a vehicle's flight dynamics reactions be modeled, at least at the highest level, as aerodynamic, propulsive, and landing/arresting/launch gear models. This is common practice in most aircraft simulation environments familiar to the authors.

6.5.4. Date format in DAVE-ML


The recommended way of representing dates in DAVE-ML documentation, especially date attributes and creation date elements, is numerically in the order YYYY-MM-DD. Thus, July 15, 2003 is given as 2003-07-15. This formatting convention conforms to the ISO-8601 standard for representing dates. [ISO8601]

6.5.5. Common sign convention notation

A convention for indicating positive sign conventions for measurements is included in Annex A of the draft AIAA Flight Dynamics Model Exchange Standard [AIAA10]. These acronyms, if applicable, should be used whenever possible to enhance communications.

6.5.6. Units-of-measure abbreviation

Each variable definition includes a mandatory `units` attribute. This attribute gives the units-of-measure for the signal represented by the variable and either 'nd' (for non-dimensional) or blank

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 257 of 343 |

DAVE-ML 2

if the signal is a dimensionless quantity or flag. In addition, the use of 'fract' to indicate a fraction (0-1) or 'pct' to indicate a percentage (0-100 or more) is encouraged.

Informally, this attribute can take on any reasonable abbreviation for a set of units that might be understandable by the intended audience, in either set of units (English or ISO). For greater re-usability, it is recommended that the set of measurements listed in the *ALAA Flight Dynamics Model Exchange Standard* [AIAA10] (of which this document is a part) be used. The Standard recommends how to encode powers of units (f_s2 for ft/sec^2, for example).

6.5.7. Internal identifiers

Identifiers are used throughout DAVE-ML to connect signals, functions, modification records and reference documents with each other, e.g., utID, gtID, bpID, refID, etc. These identifiers are character strings that must comply with the XML specification for Names [W3C-XML]. They must start with a character or underbar, may not start with "xml" or "XML," and may not contain colons, among other restrictions. In addition, the identifiers must be unique within a single DAVE-ML file. See the XML [W3C-XML] (p. 132) for more information regarding valid XML Names.

6.5.8. DAVE-ML Namespace

The XML standard allows for namespace domains, in which element names belong to either the empty (null) namespace or to a namespace that belongs to a particular XML grammar. Namespaces are identified by a uniform resource identifier (URI) that is fashioned, similar to a URL, in order that uniqueness is guaranteed.

The DAVE-ML namespace should be defined in the top-level element as follows:

```
<DAVEfunc xmlns="http://daveml.org/2010/DAVEML">
```


This will allow DAVE-ML models to be embedded in other XML documents without confusion. Note that this general URI is not a URL; HTTP queries at that address may not lead to any useful information.

The `reference` element can include two elements that belong to the World-Wide Web Consortium (W3C)'s XLINK protocol [W3C-XLINK]; they are defined with an `xlink:` prefix which actually refers to the namespace uniquely defined with the `http://www.w3.org/1999/xlink` URI. If external links to documents will be included in a DAVE-ML document, the top-level element (currently `reference`) *must* include a namespace declaration (which looks like, but technically is not, an attribute):

```
<reference xmlns:xlink="http://www.w3.org/1999/xlink">
```

Similarly, the MathML-2 elements are normally defined in a MathML namespace, so any calculation defined using MathML-2 notation should be conducted inside the MathML namespace:

```
<math xmlns="http://www.w3.org/1998/Math/MathML">
```



| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 258 of 343 |

DAVE-ML 2

6.6. Planned major elements

Additional major elements may be defined to support the goal of rapid exchange of simulation models, including


- Support for vector and matrix variables and math operations.
- Subsystem models, to support hierarchical decomposition and problem abstraction.
- State variables, both discrete and continuous, to support dynamic models.
- Dynamic (time-history) data file format, to allow for validation check-cases for dynamic models

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 259 of 343 |

DAVE-ML 2

7. Further information

Further information, background, and the latest DTD and example models of some aircraft data packages can be found at the DAVE-ML web site: <http://daveml.org>

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 260 of 343 |


DAVE-ML 2

8. Element references and descriptions

This section lists the XML tags, or elements, that make up the DAVE-ML grammar. They are listed alphabetically in two sub-sections; the first is a short description of each element; the second sub-section gives details on the element, attributes, and sub-elements.


8.1. Alphabetical list of elements

| | |
|-----------------|---|
| address | Street address or other contact information of an author [Deprecated.] |
| author | Gives name and contact information for originating party of the associated data |
| bounds | Describes limits or standard deviations of statistical uncertainties |
| bpRef | Reference to a breakpoint definition |
| bpVals | String of white space- or comma-separated values of breakpoints |
| breakpointDef | Defines breakpoint sets to be used in model |
| breakpointRefs | A list of breakpoint reference (bpRefs) |
| calculation | Used to delimit a MathML v2 calculation |
| checkData | Gives verification data for encoded model |
| checkInputs | Lists input values for check case |
| checkOutputs | Lists output values for check case |
| confidenceBound | Defines the confidence in a function [Deprecated] |
| contactInfo | Provides multiple contact information associated with an author or agency |
| correlatesWith | Identifies other functions or variables whose uncertainty correlates with our random value |
| correlation | Indicates the linear correlation of this function's or variable's randomness with a previously computed random variable |
| creationDate | Gives date of creation of entity |
| dataPoint | Defines each point of an ungridded table |
| dataTable | Lists the values of a table of function or uncertainty data |
| DAVEfunc | Root level element |

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 261 of 343 |

DAVE-ML 2

| | |
|----------------------|--|
| dependentVarPts | Defines output breakpoint values |
| dependentVarRef | Identifies the signal to be associated with the output of a function |
| description | Verbal description of an entity |
| documentRef | Reference to an external document |
| extraDocRef | Allows multiple documents to be associated with a single modification event |
| fileCreationDate | Gives date of creation of entity [Deprecated] |
| fileHeader | States source and purpose of file |
| fileVersion | Indicates the version of the document |
| function | Defines a function by combining independent variables, breakpoints, and tables |
| functionCreationDate | Date of creation of a function table [Deprecated] |
| functionDefn | Defines a function by associating a table with other information |
| griddedTable | Definition of a gridded table; associates breakpoint data with table data [Deprecated] |
| griddedTableDef | Defines an orthogonally gridded table of data points |
| griddedTableRef | Reference to a gridded table definition |
| independentVarPts | Simple definition of independent breakpoints |
| independentVarRef | References a predefined signal as an input to a function |
| internalValues | A dump of internal model values for debugging check-cases |
| isControl | Flag to identify a model control parameter |
| isDisturbance | Flag to identify a model disturbance input |
| isInput | Flag to identify a model input variable |
| isOutput | Flag to identify non-obvious output signals from model |
| isState | Flag to identify a state variable within a dynamic model |
| isStateDeriv | Flag to identify a state derivative within a dynamic model |
| isStdAIAA | Flag to identify standard AIAA simulation variable |


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 262 of 343 |

DAVE-ML 2

| | |
|--------------------|--|
| modificationRecord | To associate a reference single letter with a modification event |
| modificationRef | Reference to associated modification information |
| normalPDF | Defines a normal (Gaussian) probability density function |
| provenance | Describes origin or history of the associated information |
| provenanceRef | References a previously defined data provenance description |
| reference | Describes an external document |
| signal | Documents an internal DAVE-ML signal (value, units, etc.) |
| signalID | Gives the internal identifier of a varDef [Deprecated] |
| signalName | Gives the external name of an input or output signal |
| signalUnits | Gives the unit-of-measure of an input or output variable |
| signalValue | Gives the value of a check-case signal/variable |
| staticShot | Used to check the validity of the model once instantiated by the receiving facility or tool. |
| tol | Specifies the tolerance of value matching for model verification |
| uncertainty | Describes statistical uncertainty bounds and any correlations for a parameter or function table. |
| ungriddedTable | Definition of an ungridded set of function data [Deprecated] |
| ungriddedTableDef | Defines a table of data, each with independent coordinates |
| ungriddedTableRef | Reference to an ungridded table |
| uniformPDF | Defines a uniform (constant) probability density function |
| variableDef | Defines signals used in DAVE-ML model |
| variableRef | Reference to a variable definition |
| varID | Gives the internal identifier of a varDef |

8.2. Element descriptions

This section lists each element in detail, giving the name, content model, attributes, possible parent elements, allowable children elements, and any future plans for the element (such as deprecation).

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 263 of 343 |

DAVE-ML 2

address

address — Street address or other contact information of an author [Deprecated.]

Content model

```
address :
  {#PCDATA}
```

Attributes

NONE

Possible parents


author

Allowable children

NONE

Future plans for this element

This element has been subsumed by the contactInfo element below.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 264 of 343 |

DAVE-ML 2

author

author — Gives name and contact information for originating party of the associated data

Content model

```
author : name, org, [xns], [email]
        (address* | contactInfo*)
```

Attributes

| | |
|-------|--|
| name | The name of the author or last modifier of the associated element's data. |
| org | The author's organization. |
| xns | (optional) (deprecated) The eXtensible Name Service identifier for the author. |
| email | (optional) (deprecated) The e-mail address for the primary author. |

Description

author includes alternate means of identifying author using XNS or normal e-mail/address. The address sub-element is to be replaced with the more complete contactInfo sub-element.

Possible parents


```
fileHeader
modificationRecord
provenance
```

Allowable children

```
address
contactInfo
```

Future plans for this element

Both the xns and email attributes are deprecated and will be removed. XNS was a proposed Internet technology (eXtensible Name Service) to reduce spam that didn't catch on. It is replaced with the 'iname' sub-element as a single means to identify an individual or corporation in lieu of typical (and quickly dated) e-mail, phone, or address information. The address element itself is deprecated and should be replaced with the contactInfo element

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 265 of 343 |

DAVE-ML 2

bounds

bounds — Describes limits or standard deviations of statistical uncertainties

Content model

```

bounds :
  (#PCDATA | dataTable | variableDef | variableRef)*

```

Attributes

NONE

Description

This element contains some description of the statistical limits to the values the citing parameter element might take on. This can be in the form of a scalar value, a private dataTable, or a variableRef. In the more common instance, this element will either be a scalar constant value or a simple table whose dimensions must match the parent nominal function table and whose independent variables are identical to the nominal table. It is also possible that this limit be determined by an independent variable, either previously defined or defined in-line with this element. It does not make sense to have a dataTable cited if this bounds element is associated with anything other than an identically shaped function table.

Possible parents

```

normalPDF
uniformPDF


```

Allowable children

```

dataTable
variableDef
variableRef

```

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 266 of 343 |

DAVE-ML 2

bpRef

bpRef — Reference to a breakpoint definition

Content model

bpRef : bpID
EMPTY

Attributes

bpID The internal identifier for a breakpoint set definition.

Description


The bpRef element provides references to a previously-defined breakpoint set so breakpoints can be defined separately from, and reused by, several data tables.

Possible parents

breakpointRefs

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 267 of 343 |

DAVE-ML 2

bpVals

bpVals — String of white space- or comma-separated values of breakpoints

Content model

```
bpVals :
  {#PCDATA}
```

Attributes

NONE

Description


bpVals is a set of breakpoints (i.e., a set of independent variable values associated with one dimension of a gridded table of data). An example would be the Mach or angle-of-attack values that define the coordinates of each data point in a 2D coefficient value table.

Possible parents

breakpointDef

Allowable children

NONE

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 268 of 343 |

DAVE-ML 2

breakpointDef

breakpointDef — Defines breakpoint sets to be used in model

Content model

```
breakpointDef : [name], bpID, [units]
               description?
               bpVals
```

Attributes

name (optional) The name of the breakpoint set.

bpID The internal identifier for the breakpoint set.

units (optional) The units of measure for the breakpoint set.

Description


A breakpointDef lists gridded table breakpoints. Since these are separate from function data they may be reused.

Possible parents

DAVEfunc

Allowable children

```
description
bpVals
```

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 269 of 343 |

DAVE-ML 2

breakpointRefs

breakpointRefs — A list of breakpoint reference (bpRefs)

Content model

```
breakpointRefs :
  bpRef+
```

Attributes

NONE

Description


The breakpointRefs elements tie the independent variable names for the function to specific breakpoint values defined earlier.

Possible parents

```
griddedTableDef
griddedTable
```

Allowable children

```
bpRef
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 270 of 343 |

DAVE-ML 2

calculation

calculation — Used to delimit a MathML v2 calculation

Content model

```
calculation :
  math (p. 15)
```

Attributes

NONE

Description


The calculation element is MathML 2 content markup describing how the signal is calculated. The calculation may include both constants and variables; other variables are included by using their varID string in a MathML content identifier (ci) element.

Possible parents

```
variableDef
```

Allowable children

```
math (p. 15)
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 271 of 343 |

DAVE-ML 2

checkData

checkData — Gives verification data for encoded model

Content model

```
checkData :
  (provenance | provenanceRef)?
  staticShot+
```

Attributes

NONE

Description


This top-level element is the place-holder for verification data of various forms for the encoded model. It will include static check cases, trim shots, and dynamic check case information. The provenance sub-element is now deprecated and has been moved to individual staticShots; it is allowed here for backwards compatibility.

Possible parents

DAVEfunc

Allowable children

```
provenance
provenanceRef
staticShot
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 272 of 343 |

DAVE-ML 2

checkInputs

checkInputs — Lists input values for check case

Content model

```
checkInputs :
    signal+
```

Attributes

NONE

Description


Specifies the contents of the input vector for the given check case.

Possible parents

```
staticShot
```

Allowable children

```
signal
```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 273 of 343 |

DAVE-ML 2

checkOutputs

checkOutputs — Lists output values for check case

Content model

```
checkOutputs :
    signal+
```

Attributes

NONE

Description


Specifies the contents of the output vector for the given check case.

Possible parents

```
staticShot
```

Allowable children

```
signal
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 274 of 343 |

DAVE-ML 2

confidenceBound

confidenceBound — Defines the confidence in a function [Deprecated]

Content model

```
confidenceBound : value
EMPTY
```

Attributes

value Percent confidence (like 95%) in the function.

Description

The confidenceBound element is used to declare the confidence interval associated with the data table. This is a place-holder and will be removed in a future version of DAVE-ML.

Possible parents


```
griddedTable
ungriddedTable
```

Allowable children

NONE

Future plans for this element

Deprecated. Used only in deprecated [un]griddedTable elements. Use uncertainty element instead.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 275 of 343 |

DAVE-ML 2

contactInfo

contactInfo — Provides multiple contact information associated with an author or agency

Content model

```
contactInfo : [contactInfoType], [contactLocation]
              {#PCDATA}
```

Attributes

contactInfoType (optional) Indicates type of information being conveyed (enumerated).

- address
- phone
- fax
- email
- iname
- web

contactLocation (optional) Indicates which location is identified. Default is professional (enumerated).

- professional
- personal
- mobile

Description


Used to provide contact information about an author. Use contactInfoType to differentiate what information is being conveyed and contactLocation to denote location of the address.

Possible parents

author

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 276 of 343 |

DAVE-ML 2

correlatesWith

correlatesWith — Identifies other functions or variables whose uncertainty correlates with our random value

Content model

```
correlatesWith : varID
                EMPTY
```

Attributes

varID Identifies the variable or function output that will depend on this function's or variable's randomness.

Description


When present, this element indicates the parent function or variable is correlated with the referenced other function or variable in a linear sense. This alerts the application that the random number used to calculate this function's or variable's immediate value will be used to calculate another function's or variable's value.

Possible parents

```
normalPDF
```

Allowable children

```
NONE
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 277 of 343 |

DAVE-ML 2

correlation

correlation — Indicates the linear correlation of this function's or variable's randomness with a previously computed random variable

Content model

```
correlation : varID, corrCoef
            EMPTY
```

Attributes

| | |
|-----------------|---|
| varID | Identifies the variable or function output that helps determine the value of this random variable or function. |
| corrCoef | Indicates the amount of correlation between this variable and the referenced variable. The value should be between #1 and +1; 0 indicates no correlation, +1 indicates perfect correlation and #1 indicates inverse (negative) correlation. |

Description


When present, this element indicates the parent function or variable is correlated with the referenced other function or variable in a linear sense and gives the correlation coefficient for determining this function's random value based upon the correlating function(s)'s random value.

Possible parents

```
normalPDF
```

Allowable children

```
NONE
```


| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 278 of 343 |

DAVE-ML 2

creationDate

creationDate — Gives date of creation of entity

Content model

```
creationDate : date
EMPTY
```

Attributes

date The date of creation of the entity, in ISO 8601 (YYYY-MM-DD) format.

Description


creationDate is simply a string with a date in it. We follow ISO 8601 and use dates like "2004-01-02" to refer to January 2, 2004.

Possible parents

```
fileHeader
provenance
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 279 of 343 |

DAVE-ML 2

dataPoint

dataPoint — Defines each point of an ungridded table

Content model

```
dataPoint : [modID]
            {#PCDATA}
```

Attributes

modID (optional) The internal identifier for a modification record.

Description


The dataPoint element is used by ungridded tables to list the values of independent variables that are associated with each value of dependent variable. For example: <dataPoint> 0.1, -4.0, 0.2 <!-- Mach, alpha, CL --> </dataPoint> <dataPoint> 0.1, 0.0, 0.6 <!-- Mach, alpha CL --> </dataPoint> Each data point may have associated with it a modification tag to document the genesis of that particular point. No requirement on ordering of independent variables is implied. Since this is an ungridded table, the interpreting application is required to handle what may be unsorted data.

Possible parents

```
ungriddedTableDef
ungriddedTable
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 280 of 343 |

DAVE-ML 2

dataTable

dataTable — Lists the values of a table of function or uncertainty data

Content model

```
dataTable :
  (#PCDATA)
```

Attributes

NONE

Description


The dataTable element is used by gridded tables where the indep. variable values are implied by breakpoint sets. Thus, the data embedded between the dataTable element tags is expected to be sorted ASCII values of the gridded table, wherein the last independent variable listed in the function header varies most rapidly. The table data point values are specified as comma- or white space-separated values in conventional floating-point notation (0.93638E-06) in a single long sequence as if the table had been unraveled with the last-specified dimension changing most rapidly. Line breaks are to be ignored. Comments may be embedded in the table to promote [human] readability, with appropriate escaping characters. A dataTable element can also be used in an uncertainty element to provide duplicate uncertainty bound values.

Possible parents

```
griddedTableDef
griddedTable
bounds
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 281 of 343 |

DAVE-ML 2

DAVEfunc

DAVEfunc — Root level element

Content model

```
DAVEfunc : xmlns
  fileHeader
  variableDef+
  breakpointDef*
  griddedTableDef*
  ungriddedTableDef*
  function*
  checkData?
```

Attributes

xmlns This attribute specifies that the default namespace for un-prefixed elements is this DTD.

Description


Root element is DAVEfunc, composed of a file header element followed by one or more variable definitions and zero or more breakpoint definitions, gridded or ungridded table definitions, and function elements.

Possible parents

NONE - ROOT ELEMENT

Allowable children

```
fileHeader
variableDef
breakpointDef
griddedTableDef
ungriddedTableDef
function
checkData
```

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 282 of 343 |

DAVE-ML 2

dependentVarPts

dependentVarPts — Defines output breakpoint values

Content model

```
dependentVarPts : varID, [name], [units], [sign]
                (#PCDATA)
```

Attributes

varID The internal identifier of the output signal this table should drive.

name (optional) The name of the function's dependent variable output signal.

units (optional) The units of measure for the dependent variable.

sign (optional) The sign convention for the dependent variable.

Description


A dependentVarPts element is a simple comma- or white space-delimited list of function values and contains a mandatory varID as well as optional name, units, and sign convention attributes. Data points are arranged as single vector with last-specified breakpoint values changing most frequently. Note that the number of dependent values must equal the product of the number of independent values for this simple, gridded, realization. This element is used for simple functions that do not share breakpoint or table values with other functions.

Possible parents

function

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 283 of 343 |

DAVE-ML 2

dependentVarRef

dependentVarRef — Identifies the signal to be associated with the output of a function

Content model

```
dependentVarRef : varID
EMPTY
```

Attributes

varID The internal identifier for the output signal.

Description


A dependentVarRef ties the output of a function to a signal name defined previously in a variable definition.

Possible parents

function

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 284 of 343 |

DAVE-ML 2

description

description — Verbal description of an entity

Content model

```
description :
  {#PCDATA}
```

Attributes

NONE

Description


The description element is a textual description of an entity. The full UNICODE character set is supported by XML but may not be available in all processing applications.

Possible parents

```
fileHeader
variableDef
breakpointDef
griddedTableDef
ungriddedTableDef
function
reference
modificationRecord
provenance
staticShot
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 285 of 343 |

DAVE-ML 2

documentRef

documentRef — Reference to an external document

Content model

```
documentRef : [docID], refID
EMPTY
```

Attributes

docID (optional) (deprecated) The internal identifier of a reference definition element.

refID The internal identifier of a reference definition element.

Possible parents


provenance

Allowable children

NONE

Future plans for this element

The 'docID' attribute is deprecated; it has been renamed 'refID' to match its use in the 'reference' element. This attribute will be removed in a future version of DAVE-ML.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 286 of 343 |

DAVE-ML 2

extraDocRef

extraDocRef — Allows multiple documents to be associated with a single modification event

Content model

```
extraDocRef : refID
EMPTY
```

Attributes

refID The internal identifier of a reference definition element.

Description


A single modification event may have more than one documented reference. This element can be used in place of the refID attribute in a modificationRecord to record more than one refIDs, pointing to the referenced document.

Possible parents

modificationRecord

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 287 of 343 |

DAVE-ML 2

fileCreationDate

fileCreationDate — Gives date of creation of entity [Deprecated]

Content model

```
fileCreationDate : date
EMPTY
```

Attributes

date The date of the file, in ISO 8601 (YYYY-MM-DD) format.

Description

fileCreationDate is simply a string with a date in it. We follow ISO 8601 and use dates like "2004-01-02" to refer to January 2, 2004. Its use is now deprecated in favor of the simpler creationDate.

Possible parents


```
fileHeader
```

Allowable children

```
NONE
```

Future plans for this element

The fileCreationDate and functionCreationDate have been replaced with a new creationDate multipurpose element.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 288 of 343 |

DAVE-ML 2

fileHeader

fileHeader — States source and purpose of file

Content model

```

fileHeader : [name]
  author*
  (creationDate | fileCreationDate)
  fileVersion?
  description?
  reference*
  modificationRecord*
  provenance*

```

Attributes

name (optional) The name of the file.

Description

The header element requires at least one author and a creation date; optional content includes version indicator, description, references, and modification records.

Possible parents


DAVEfunc

Allowable children

```

author
creationDate
fileCreationDate
fileVersion
description
reference
modificationRecord
provenance

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 289 of 343 |

DAVE-ML 2

fileVersion

fileVersion — Indicates the version of the document

Content model

```
fileVersion :
  {#PCDATA}
```

Attributes

NONE

Description


This is a string describing, in some arbitrary text, the version identifier for this function description.

Possible parents

```
fileHeader
```

Allowable children

NONE

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 290 of 343 |

DAVE-ML 2

function

function — Defines a function by combining independent variables, breakpoints, and tables

Content model

```

function : name
  description?
  (provenance | provenanceRef)?
  {
    independentVarPts+
    dependentVarPts
  }
OR
  {
    independentVarRef+
    dependentVarRef
    functionDefn
  }

```

Attributes

name The name of this function.

Description

Each function has optional description, optional provenance, and either a simple input/output table values or references to more complete (possible multiple) input, output, and function data elements.

Possible parents


DAVEfunc

Allowable children

```

description
provenance
provenanceRef
independentVarPts
dependentVarPts
independentVarRef
dependentVarRef
functionDefn

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 291 of 343 |

DAVE-ML 2

functionCreationDate

functionCreationDate — Date of creation of a function table [Deprecated]

Content model

```
functionCreationDate : date
EMPTY
```

Attributes

date The creation date of the function, in ISO 8601 (YYYY-MM-DD) format.

Description

functionCreationDate is simply a string with a date in it. We follow ISO 8601 and use dates like "2004-01-02" to refer to January 2, 2004. Its use is now deprecated in favor of the simpler creationDate.

Possible parents


provenance

Allowable children

NONE

Future plans for this element

The fileCreationDate and functionCreationDate have been replaced with a new creationDate multipurpose element.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 292 of 343 |

DAVE-ML 2

functionDefn

functionDefn — Defines a function by associating a table with other information

Content model

```
functionDefn : {name}
               (griddedTableRef | griddedTableDef | griddedTable | ungriddedTableRef
                | ungriddedTableDef | ungriddedTable)
```

Attributes

name (optional) The name of this function definition.

Description


A functionDefn defines how function is represented in one of two possible ways: gridded (implies breakpoints) or ungridded (with explicit independent values for each point).

Possible parents

function

Allowable children

```
griddedTableRef
griddedTableDef
griddedTable
ungriddedTableRef
ungriddedTableDef
ungriddedTable
```


| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 293 of 343 |

DAVE-ML 2

griddedTable

griddedTable — Definition of a gridded table; associates breakpoint data with table data
[Deprecated]

Content model

```
griddedTable : [name]
  breakpointRefs
  confidenceBound?
  dataTable
```

Attributes

name (optional) The name of the gridded table being defined.

Possible parents


functionDefn

Allowable children

```
breakpointRefs
confidenceBound
dataTable
```

Future plans for this element

Deprecated. Use griddedTableDef instead.

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 294 of 343 |

DAVE-ML 2

griddedTableDef

griddedTableDef — Defines an orthogonally gridded table of data points

Content model

```
griddedTableDef : [name], [gtID], [units]
  description?
  (provenance | provenanceRef)?
  breakpointRefs
  uncertainty?
  dataTable
```

Attributes

name (optional) The name of the gridded table.

gtID (optional) An internal identifier for the table. Required if table is to be reused by another function or is defined outside of a function.

units (optional) Units of measure for the table values.

Description


A griddedTableDef contains points arranged in an orthogonal (but multi-dimensional) array, where the independent variables are defined by separate breakpoint vectors. This table definition may be specified separately from the actual function declaration; if so, it requires a gtID identifier attribute so that it may be used by multiple functions.

Possible parents

```
DAVEfunc
functionDefn
```

Allowable children

```
description
provenance
provenanceRef
breakpointRefs
uncertainty
dataTable
```

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 295 of 343 |

DAVE-ML 2

griddedTableRef

griddedTableRef — Reference to a gridded table definition

Content model

```
griddedTableRef : gtID
EMPTY
```

Attributes


gtID The internal identifier of a gridded table definition.

Possible parents

functionDefn

Allowable children

NONE

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 296 of 343 |

DAVE-ML 2

independentVarPts

independentVarPts — Simple definition of independent breakpoints

Content model


```
independentVarPts : varID, [name], [units], [sign], [extrapolate], [interpolate]
                    (#PCDATA)
```

Attributes

| | |
|-------------|--|
| varID | The internal identifier of the input signal corresponding to this independent variable. |
| name | (optional) The name of the function's independent variable input signal. |
| units | (optional) The units of measure for the independent variable. |
| sign | (optional) The sign convention for the independent variable. |
| extrapolate | (optional) Extrapolation flags for IV out-of-bounds (default is neither) (enumerated). <ul style="list-style-type: none"> • neither • min • max • both |
| interpolate | (optional) Interpolation flags for independent variable (default is linear) (enumerated). <ul style="list-style-type: none"> • discrete • floor • ceiling • linear • quadraticSpline • cubicSpline |

Description

An independentVarPts element is a simple white space- or comma-separated list of breakpoints and contains a mandatory varID identifier as well as optional name, units, and sign convention

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 297 of 343 |

DAVE-ML 2


attributes. An optional extrapolate attribute describes how to extrapolate the output value when the input value exceeds specified values (default is 'neither,' meaning the value of the table is held constant at the nearest defined value). An optional interpolate attribute indicates how to perform the interpolation within the table (supporting discrete, linear, cubic or quadratic splines). There are three different discrete options: 'discrete' means nearest-neighbor, with an exact mid-point value being rounded in the positive direction; 'ceiling' means the function takes on the value associated with the next (numerically) higher independent breakpoint as soon as the original value is exceeded; and 'floor' means the function holds the value associated with each breakpoint until the next (numerically) higher breakpoint value is reached by the independent argument. The default interpolation attribute value is 'linear.' This element is used for simple functions that do not share breakpoint or table values with other functions.

Possible parents

function

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 298 of 343 |

DAVE-ML 2

independentVarRef

independentVarRef — References a predefined signal as an input to a function

Content model


```
independentVarRef : varID, [min], [max], [extrapolate], [interpolate]
EMPTY
```

Attributes

| | |
|-------------|--|
| varID | The internal identifier for the input signal. |
| min | (optional) The allowable lower limit for the input signal. |
| max | (optional) The allowable upper limit for the input signal. |
| extrapolate | (optional) Extrapolation flags for IV out-of-bounds (default is neither) (enumerated). <ul style="list-style-type: none"> • neither • min • max • both |
| interpolate | (optional) Interpolation flags for independent variable (default is linear) (enumerated). <ul style="list-style-type: none"> • discrete • floor • ceiling • linear • quadraticSpline • cubicSpline |

Description

An independentVarRef more fully describes the input mapping of the function by pointing to a separate breakpoint definition element. An optional extrapolate attribute describes how to extrapolate the output value when the input value exceeds specified values (default is 'neither,')

| | | | |
|---|---|--|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 299 of 343 |

DAVE-ML 2


meaning the value of the table is held constant at the nearest defined value). An optional interpolate attribute indicates how to perform the interpolation within the table (supporting discrete, linear, cubic or quadratic splines). There are three different discrete options: 'discrete' means nearest-neighbor, with an exact mid-point value being rounded in the positive direction; 'floor' means the function takes on the value associated with the next (numerically) higher independent breakpoint as soon as original value is exceeded; and 'ceiling' means the function holds the value associated with each breakpoint until the next (numerically) higher breakpoint value is reached by the independent argument. The default interpolation attribute value is 'linear.' This element allows reuse of common breakpoint values for many tables but with possible differences in interpolation or extrapolation for each use.

Possible parents

function

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 300 of 343 |

DAVE-ML 2

internalValues

internalValues — A dump of internal model values for debugging check-cases

Content model

```
internalValues :
    signal+
```

Attributes

NONE

Description


Provides a set of all internal variable values to assist in debugging recalcitrant implementations of DAVE-ML import tools.

Possible parents

```
staticShot
```

Allowable children

```
signal
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 301 of 343 |

DAVE-ML 2

isControl

isControl — Flag to identify a model control parameter

Content model

```
isControl :
  EMPTY
```

Attributes

NONE

Description


The presence of an isControl element indicates that this signal is a simulation control parameter used to vary the operation of the model, e.g. the time step size. Such parameters should be ignored when performing linear model extraction (for example) and should not significantly modify the dynamic behavior of the model.

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 302 of 343 |

DAVE-ML 2

isDisturbance

isDisturbance — Flag to identify a model disturbance input

Content model

```
isDisturbance :  
  EMPTY
```

Attributes

NONE

Description


The presence of an isDisturbance element indicates that this signal is an external disturbance input to the model and can be ignored when performing linear model extraction (for example). Such parameters should not significantly modify the nominal dynamic behavior of the model.

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 303 of 343 |

DAVE-ML 2

isInput

isInput — Flag to identify a model input variable

Content model

```
isInput :
  EMPTY
```

Attributes

NONE

Description


The presence of an isInput element indicates that this variable is an input signal to the model.

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 304 of 343 |

DAVE-ML 2

isOutput

isOutput — Flag to identify non-obvious output signals from model

Content model

```
isOutput :  
  EMPTY
```

Attributes

NONE

Description


The presence of the isOutput element indicates that this variable should be forced to be an output, even if it is used internally as an input elsewhere. Otherwise, the processing program may assume a signal defined with a calculation and used subsequently in the model is only an internal signal.

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 305 of 343 |

DAVE-ML 2

isState

isState — Flag to identify a state variable within a dynamic model

Content model

```
isState :
    EMPTY
```

Attributes

NONE

Description


The presence of an isState element indicates that this variable is one of possibly multiple state variables in a dynamic model; this tells the processing entity that this is the output of an integrator (for continuous models) or a discretely updated state (for discrete models).

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 306 of 343 |

DAVE-ML 2

isStateDeriv

isStateDeriv — Flag to identify a state derivative within a dynamic model

Content model

```
isStateDeriv :
  EMPTY
```

Attributes

NONE

Description


The presence of an isStateDeriv element indicates that this variable is one of possibly several state derivative variables in a dynamic model; this tells the processing entity that this is the output of an integrator (for continuous models only).

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 307 of 343 |

DAVE-ML 2

isStdAIAA

isStdAIAA — Flag to identify standard AIAA simulation variable

Content model

```
isStdAIAA :
  EMPTY
```

Attributes

NONE

Description


The presence of an isStdAIAA element indicates that this variable is one of the standard AIAA variable names which should be recognizable exterior to this module (e.g. AngleOfAttack_deg). This flag should assist importing tools in determining when an input or output should match a facility-provided signal name without requiring further information.

Possible parents

```
variableDef
```

Allowable children

NONE

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 308 of 343 |

DAVE-ML 2

modificationRecord

modificationRecord — To associate a reference single letter with a modification event

Content model

```

modificationRecord : modID, date, [refID]
    author*
    description?
    extraDocRef*

```

Attributes

| | |
|-------|--|
| modID | A single letter used to identify all modified data associated with this modification record. |
| date | The date of the modification, in ISO 8601 (YYYY-MM-DD) format. |
| refID | (optional) A reference to a predefined document that describes the reason for this modification. |

Description

A modificationRecord associates a single letter (such as modification "A") with modification author(s), address, and any optional external reference documents, in keeping with the AIAA draft standard.

Possible parents


```
fileHeader
```

Allowable children

```

author
description
extraDocRef

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 309 of 343 |

DAVE-ML 2

modificationRef

modificationRef — Reference to associated modification information

Content model

```
modificationRef : modID
EMPTY
```

Attributes


modID The internal identifier of a modification definition.

Possible parents

provenance

Allowable children

NONE

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 310 of 343 |

DAVE-ML 2

normalPDF

normalPDF — Defines a normal (Gaussian) probability density function

Content model

```
normalPDF : numSigmas
           bounds
           correlatesWith*
           correlation*
```

Attributes

numSigmas Indicates how many standard deviations is represented by the uncertainty values given later. Integer value > 0.

Description


In a normally distributed random variable, a symmetrical distribution of given standard deviation is assumed about the nominal value (which is given elsewhere in the parent element). The correlatesWith sub-element references other functions or variables that have a linear correlation to the current parameter or function. The correlation sub-element specifies the correlation coefficient and references the other function or variable whose random value helps determine the value of this parameter.

Possible parents

```
uncertainty
```

Allowable children

```
bounds
correlatesWith
correlation
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 311 of 343 |

DAVE-ML 2

provenance

provenance — Describes origin or history of the associated information

Content model

```
provenance : {provID}
  author*
  (creationDate | functionCreationDate)
  documentRef*
  modificationRef*
  description?
```

Attributes

provID (optional) This attribute allows the provenance information defined here to be cited elsewhere.

Description


The provenance element describes the history or source of the model data and includes author, date, and zero or more references to documents and modification records.

Possible parents

```
fileHeader
variableDef
griddedTableDef
ungriddedTableDef
function
checkData
staticShot
```

Allowable children

```
author
creationDate
functionCreationDate
documentRef
modificationRef
description
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 312 of 343 |

DAVE-ML 2

provenanceRef

provenanceRef — References a previously defined data provenance description

Content model

```
provenanceRef : provID
                EMPTY
```

Attributes

provID The internal identifier for a previously defined provenance.

Description


When the provenance of a set of several data is identical, the first provenance element should be given a provID and referenced by later provenanceRef elements.

Possible parents

```
variableDef
griddedTableDef
ungriddedTableDef
function
checkData
staticShot
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 313 of 343 |

DAVE-ML 2

reference

reference — Describes an external document

Content model

```
reference : xmlns:xlink, xlink:type, refID, author, title, [classification],
[accession], date, [xlink:href]
description?
```

Attributes

| | |
|----------------|---|
| xmlns:xlink | The value of this attribute must be "http://www.w3.org/1999/xlink". If omitted, it should be provided by the parser since it is specified in the DTD. |
| xlink:type | The value of this attribute must be "simple". If omitted, it should be provided by the parser since it is specified in the DTD. |
| refID | An internal identifier for this reference definition. |
| author | The name of the author of the reference. |
| title | The title of the referenced document. |
| classification | (optional) The security classification of the document. |
| accession | (optional) The accession number (ISBN or organization report number) of the document. |
| date | The date of the document, in ISO 8601 (YYYY-MM-DD) format. |
| xlink:href | (optional) A URL to an on-line copy of the referenced document. |

Description


This element gives identifying (citation) information to an external, possibly on-line, reference document, including a user-specified author, title, classification, accession number, date and URL.

Possible parents

fileHeader

Allowable children

description

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 314 of 343 |

DAVE-ML 2

signal

signal — Documents an internal DAVE-ML signal (value, units, etc.)

Content model

```

signal :
  (
    signalName
    signalUnits
  )
OR
  (
    (varID | signalID)
  )
  signalValue
  tol?

```

Attributes

NONE

Description

This element is used to document the name, ID, value, tolerance, and units of measure for check-cases. When used with checkInputs or checkOutputs, the signalName sub-element must be present (since check cases are viewed from "outside" the model); when used in an internalValues element, the varID sub-element should be used to identify the signal by its model-unique internal reference. When used in a checkOutputs vector, the tol element must be present. Tolerance is specified as a maximum absolute difference between the expected and actual value. The signalID sub-element is now deprecated in favor of the more consistent varID.

Possible parents

```

checkInputs
internalValues
checkOutputs


```

Allowable children

```

signalName
signalUnits
varID
signalID
signalValue
tol

```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 315 of 343 |

DAVE-ML 2

signalID

signalID — Gives the internal identifier of a varDef [Deprecated]

Content model

```
signalID :
  (#PCDATA)
```

Attributes

NONE

Description

Used to specify the input or output varID. Now deprecated; reuse of varID is best practice.

Possible parents


signal

Allowable children

NONE

Future plans for this element

The signalID element has been deprecated with 2.0 in favor of the more consistent varID element and will be unsupported in a future release of this specification.

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 316 of 343 |

DAVE-ML 2

signalName

signalName — Gives the external name of an input or output signal

Content model

```
signalName :
  {#PCDATA}
```

Attributes

NONE

Description


Used inside a checkCase element to specify the input or output variable name

Possible parents

signal

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 317 of 343 |

DAVE-ML 2

signalUnits

signalUnits — Gives the unit-of-measure of an input or output variable

Content model

```
signalUnits :
  {#PCDATA}
```

Attributes

NONE

Description


Used inside a checkCase element to specify the units-of-measure for an input or output variable, for verification of proper implementation of a model.

Possible parents

signal

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 318 of 343 |

DAVE-ML 2

signalValue

signalValue — Gives the value of a check-case signal/variable

Content model

```
signalValue :
  {#PCDATA}
```

Attributes

NONE

Description


Used to give the current value of an internal signal or input/output variable, for verification of proper implementation of a model.

Possible parents

signal

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 319 of 343 |

DAVE-ML 2

staticShot

staticShot — Used to check the validity of the model once instantiated by the receiving facility or tool.

Content model

```
staticShot : name, [refID]
  description?
  (provenance | provenanceRef)?
  checkInputs
  internalValues?
  checkOutputs
```

Attributes

name

refID (optional) Points to a reference given in the file header.

Description


Contains a description of the inputs and outputs, and possibly internal values, of a DAVE-ML model in a particular instant of time.

Possible parents

checkData

Allowable children

```
description
provenance
provenanceRef
checkInputs
internalValues
checkOutputs
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 320 of 343 |

DAVE-ML 2

tol

tol — Specifies the tolerance of value matching for model verification

Content model

```
tol :
  {#PCDATA}
```

Attributes

NONE

Description


This element specifies the allowable tolerance of error in an output value such that the model can be considered verified. It is assumed all uncertainty is removed in performing the model calculations. Tolerance is specified as a maximum absolute difference between the expected and actual value.

Possible parents

```
signal
```

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 321 of 343 |

DAVE-ML 2

uncertainty

uncertainty — Describes statistical uncertainty bounds and any correlations for a parameter or function table.

Content model

```
uncertainty : effect
              (normalPDF | uniformPDF)
```

Attributes

`effect` Indicates how uncertainty bounds are interpreted. (enumerated).

- `additive`
- `multiplicative`
- `percentage`
- `absolute`

Description


The uncertainty element is used in function and parameter definitions to describe statistical variance in the possible value of that function or parameter value. Only Gaussian (normal) or uniform distributions of continuous random variable distribution functions are supported.

Possible parents

```
variableDef
griddedTableDef
ungriddedTableDef
```

Allowable children

```
normalPDF
uniformPDF
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 322 of 343 |

DAVE-ML 2

ungriddedTable

ungriddedTable — Definition of an ungridded set of function data [Deprecated]

Content model

```
ungriddedTable : {name}
  confidenceBound?
  dataPoint+
```

Attributes

name (optional) The name of the ungridded table being defined.

Possible parents


functionDefn

Allowable children

```
confidenceBound
dataPoint
```

Future plans for this element

Deprecated. Use ungriddedTableDef instead.

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 323 of 343 |

DAVE-ML 2

ungriddedTableDef

ungriddedTableDef — Defines a table of data, each with independent coordinates

Content model

```
ungriddedTableDef : [name], [utID], [units]
  description?
  (provenance | provenanceRef)?
  uncertainty?
  dataPoint+
```

Attributes

name (optional) The name of the ungridded table.

utID (optional) An internal identifier for the table. Required if table is to be reused by another function or is defined outside of a function.

units (optional) The units of measure for the table values.

Description


An ungriddedTableDef contains points that are not in an orthogonal grid pattern; thus, the independent variable coordinates are specified for each dependent variable value. This table definition may be specified separately from the actual function declaration; if so, it requires an internal utID identifier attribute so that it may be used by multiple functions.

Possible parents

```
DAVEfunc
functionDefn
```

Allowable children

```
description
provenance
provenanceRef
uncertainty
dataPoint
```

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 324 of 343 |

DAVE-ML 2

ungriddedTableRef

ungriddedTableRef — Reference to an ungridded table

Content model

```
ungriddedTableRef : utID
    EMPTY
```

Attributes


utID The internal identifier of a ungridded table definition.

Possible parents

functionDefn

Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 325 of 343 |

DAVE-ML 2

uniformPDF

uniformPDF — Defines a uniform (constant) probability density function

Content model

```
uniformPDF :
  bounds*
```

Attributes

NONE

Description


In a uniformly distributed random variable, the value of the parameter has equal likelihood of assuming any value within the (possibly asymmetric, implied by specifying two) bounds, which must bracket the nominal value (which is given elsewhere in the parent element).

Possible parents

uncertainty

Allowable children

bounds

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 326 of 343 |

DAVE-ML 2

variableDef

variableDef — Defines signals used in DAVE-ML model

Content model

```

variableDef : name, varID, units, [axisSystem], [sign], [alias], [symbol],
[initialValue]
  description?
  (provenance | provenanceRef)?
  calculation?
  (isInput | isControl | isDisturbance)?
  isState?
  isStateDeriv?
  isOutput?
  isStdAIAA?
  uncertainty?

```

Attributes


| | |
|--------------|---|
| name | The name of the signal being defined. |
| varID | An internal identifier for the signal. |
| units | The units of the signal. |
| axisSystem | (optional) The axis in which the signal is measured. |
| sign | (optional) The sign convention for the signal, if any. |
| alias | (optional) Possible alias name (facility specific) for the signal. |
| symbol | (optional) UNICODE symbol for the signal. |
| initialValue | (optional) An initial and possibly constant numeric value for the signal. |

Description

variableDef elements provide wiring information (i.e., they identify the input and output signals used by these function blocks). They also provide MathML content markup to indicate any calculation required to arrive at the value of the variable, using other variables as inputs. The variable definition can include statistical information regarding the uncertainty of the values which it might take on, when measured after any calculation is performed. Information about the reason for inclusion or change to this element can be included in an optional provenance sub-element.

Possible parents

DAVEfunc
bounds

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 327 of 343 |


DAVE-ML 2

Allowable children

```

description
provenance
provenanceRef
calculation
isInput
isControl
isDisturbance
isState
isStateDeriv
isOutput
isStdAIAA
uncertainty

```


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 328 of 343 |

DAVE-ML 2

variableRef

variableRef — Reference to a variable definition

Content model

```
variableRef : varID
              EMPTY
```

Attributes


varID The internal identifier of a previous variable definition.

Possible parents

bounds

Allowable children

NONE

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 329 of 343 |

DAVE-ML 2

varID

varID — Gives the internal identifier of a varDef

Content model

```
varID :
  {#PCDATA}
```

Attributes

NONE

Description


Used to specify the input or output varID. Replaces earlier signalID element.

Possible parents

signal


Allowable children

NONE

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 330 of 343 |

DAVE-ML 2


The editors would like to acknowledge the contributions, encouragement and helpful suggestions for steering the evolution of DAVE-ML from the following individuals: Trey Arthur (NASA Langley Research Center), Jon Berndt (Jacobs Sverdrup), Geoff Brian (Australian DSTO), Randy Brumbaugh (Indigo Innovations), Giovanni A. Cignoni (University of Pisa), Bill Cleveland (NASA Ames Research Center), Jeremy Furtek (Delphi Research), Peter Grant (UTIAS), Missy Hill (UNISYS), Hilary Keating (Fortburn Pty. Ltd.), Dennis Linse (SAIC), J. Dana McMinn (NASA Langley Research Center), Daniel M. Newman (formerly Ball Aerospace, now Quantitative Aeronautics), Riley Rainey (SDS International), Brent York (formerly NAVAIR, now Indra Systems, Inc.), and Curtis Zimmerman (NASA Marshall Space Flight Center).

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 331 of 343 |

DAVE-ML 2


References

- [Acevedo07] : Acevedo, Amanda; Arnold, Jason; Othon, William; and Berndt, Jon : *ANTARES: Spacecraft Simulation for Multiple User Communities and Facilities*. AIAA 2007-6888, presented at the AIAA Modeling and Simulation Technologies Conference, 20 August 2007, Hilton Head, South Carolina.
- [AIAA92] : American Institute of Aeronautics and Astronautics : *American National Standard: Recommended Practice for Atmospheric and Space Flight Vehicle Coordinate Systems*. ANSI/AIAA R-004-1992
- [AIAA01] : AIAA Flight Simulation Technical Committee : “Standard Simulation Variable Names [http://daveml.nasa.gov/AIAA_stds/SimParNames_May_2007_v2.pdf]”, Draft, May 2007
- [AIAA03] : AIAA Modeling and Simulation Technical Committee : “Standards for the Exchange of Simulation Modeling Data [http://daveml.nasa.gov/AIAA_stds/SimDataExchange_Jan2003.pdf]”, Preliminary Draft, Jan 2003
- [AIAA10] : American Institute of Aeronautics and Astronautics : *American National Standard: Flight Dynamics Model Exchange Standard (Draft)* [<http://info.aiaa.org/Standards/AS/DAVE>]. BSR/AIAA S-119-201x
- [Brian05] : Brian, Geoff; Young, Michael; Newman, Daniel; Curtin, Robert; and Keating, Hilary : *The Quest for a Unified Aircraft Dataset Format* [<http://www.siaa.asn.au/get/2411855949.pdf>] . Presented at the Simulation Industry Association of Australia, 2005.
- [Durak06] : Durak, Umut; Oguztuzun, Halit; and Ider, S. Kemal : *An Ontology for Trajectory Simulation* . Proceedings of the 2006 Winter Simulation Conference, 2006.
- [Hildreth94] : Hildreth, B. L.: *A Process for the Development of Simulation Standards*. AIAA 94-3430, presented at the AIAA Flight Simulation Technologies Conference, August 1994, Baltimore, Maryland.
- [Hildreth98] : Hildreth, Bruce L.: *The Draft AIAA Flight Mechanics Modeling Standard: An Opportunity for Industry Feedback*. AIAA 98-4576, presented at the AIAA Modeling and Simulation Technologies Conference, August 1998, Boston, Massachusetts.
- [Hildreth08] : Hildreth, Bruce; Linse, Dennis J.; and Dicola, John : *Pseudo Six Degree of Freedom (6DOF) Models for Higher Fidelity Constructive Simulations*. AIAA 2008-6857, presented at the AIAA Modeling and Simulation Technologies Conference, 18 August 2008, Honolulu, Hawaii.
- [Hill07] : Hill, Melissa A.; and Jackson, E. Bruce : *The DaveMLTranslator: An Interface for DAVE-ML Aerodynamic Models* [http://http://daveml/papers/2007_AIAA_DaveMLTranslator_paper.pdf]. AIAA 2007-6890, presented at the AIAA Modeling and Simulation Technologies Conference, 20 August 2007, Hilton Head, South Carolina.
- [ISO8601] : International Organization for Standards : “Data elements and interchange formats - Information interchange - Representation of dates and times [<http://www.iso.ch/iso/en/CatalogueDetailPage.CatalogueDetail?CSNUMBER=40874&ICS1=1&ICS2=140&ICS3=30>]” ISO 8601:2000, 2000

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: | Flight Simulation Model Exchange | | Page #: 332 of 343 |

DAVE-ML 2

- [Jackson04] : Jackson, E. Bruce; Hildreth, Bruce L.; York, Brent W.; and Cleveland, William : *Evaluation of a Candidate Flight Dynamics Model Simulation Standard Exchange Format* [<http://dscb.larc.nasa.gov/DCBStaff/ebj/Papers/aiaa-04-5038-DAVEdemo1.pdf>] . AIAA 2004-5038, presented at the AIAA Modeling and Simulation Technologies Conference, 17 August 2004, Providence, Rhode Island.
- [Jackson02] : Jackson, E. Bruce; and Hildreth, Bruce L. : *Flight Dynamic Model Exchange using XML* [<http://techreports.larc.nasa.gov/ltrs/PDF/2002/aiaa/NASA-aiaa-2002-4482.pdf>] . AIAA 2002-4482, presented at the AIAA Modeling and Simulation Technology Conference, 5 August 2002, Monterey, California.
- [Lin04] : Lin, Risheng; and Afjeh, Abdollah A. : "Development of XML Databinding Integration for Web-Enabled Aircraft Engine Simulation". *J. Computing and Information Science and Engineering* 4 3 American Society of Mechanical Engineers September 2004
- [NAA64] : North American Aviation : *Aerodynamic Data Manual for Project Apollo* SLD 64-174C, 1964
- [W3C-XLINK] : World Wide Web Consortium (W3C) : "W3C Recommendation: XML Linking Language (XLink) Version 1.0 [<http://www.w3.org/TR/xlink/>]" 2001-06-27
- [W3C-XML] : World Wide Web Consortium (W3C) : "W3C Recommendation: Extensible Markup Language (XML) 1.0 [<http://www.w3.org/TR/xml/>]" 2008-11-26
- [wiki01] : Combined wisdom of the Internet : "http://wikipedia.org/wiki/Spline_interpolation: "Spline Interpolation" [http://en.wikipedia.org/wiki/Spline_interpolation]"Cited 2006

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 333 of 343 |

DAVE-ML 2


Index

A

- 'accession' attribute
 - of 'reference' element, 113
- 'address' element (deprecated)
 - as child of 'author' element, 64
 - definition, 63
 - deprecation, 9
- AIAA
 - Draft Standard S-119, 12
 - Modeling and Simulation Technical Committee, 13
 - Recommended Practice R-004-1992, 13
 - Standards, 12
 - web site, 12
- 'alias' attribute
 - of 'variableDef' element, 24, 126
- Apollo, 30
- Arthur, Jarvis A., III, 5, 6, 6, 130
- atan2, 15
- 'author' element
 - as child of 'fileHeader' element, 21, 88
 - as child of 'modificationRecord' element, 108
 - as child of 'provenance' element, 111
 - definition, 64
 - of 'reference' element, 113
- 'axisSystem' attribute
 - of 'variableDef' element, 24, 126

B

- Berndt, Jon S., 130
- 'bounds' element
 - as child of 'normalPDF' element, 110
 - as child of 'uniformPDF' element, 125
 - definition, 65
- 'bpID' attribute
 - of 'bpRef' element, 66
 - of 'breakpointDef' element, 30, 68
- 'bpRef' element
 - as child of 'breakpointRefs' element, 69
 - definition, 66
- 'bpVals' element
 - as child of 'breakpointDef' element, 30, 68
 - definition, 67
- 'breakpointDef' element
 - as child of 'DAVEfunc' element, 19, 81
 - definition, 68


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 334 of 343 |

DAVE-ML 2

example of, 31
 introduction, 16
 overview, 30
 reuse, 20
 'breakpointRefs' element
 as child of 'griddedTable' element, 93
 as child of 'griddedTableDef' element, 32, 94
 definition, 69
 Brian, Geoffrey, 7, 8, 8, 8, 8, 8, 37, 130
 Brumbaugh, Randy, 7, 130

C

'calculation' element
 as child of 'variableDef' element, 25, 127
 definition, 70
 'checkData' element
 as child of 'DAVEfunc' element, 20, 81
 definition, 71
 example of
 with internal values, 44
 without internal values, 43
 introduction, 17
 overview, 43
 'checkInputs' element
 as child of 'staticShot' element, 119
 definition, 72
 'checkOutputs' element
 as child of 'staticShot' element, 119
 definition, 73
 Cignoni, Giovanni A., 7, 130
 'classification' attribute
 of 'reference' element, 113
 Cleveland, William, 9, 10, 13, 130
 'confidenceBound' element (deprecated)
 as child of 'griddedTable' element, 93
 as child of 'ungriddedTable' element, 122
 definition, 74
 'contactInfo' element
 as child of 'author' element, 64
 definition, 75
 discussion, 9
 'contactInfoType' attribute
 of 'contactInfo' element, 75
 'contactLocation' attribute
 of 'contactInfo' element, 75
 'corrCoef' attribute
 of 'correlation' element, 77
 'correlatesWith' element
 as child of 'normalPDF' element, 110


| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 335 of 343 |

DAVE-ML 2

definition, 76
 'correlation' element
 as child of 'normalPDF' element, 110
 definition, 77
 'creationDate' element
 as child of 'fileHeader' element, 21, 88
 as child of 'provenance' element, 111
 definition, 78

D

'dataPoint' element
 as child of 'ungriddedTable' element, 122
 as child of 'ungriddedTableDef' element, 35, 123
 definition, 79
 'dataTable' element
 as child of 'bounds' element, 65
 as child of 'griddedTable' element, 93
 as child of 'griddedTableDef' element, 32, 94
 definition, 80
 'date' attribute
 of 'creationDate' element, 78
 of 'fileCreationDate' element, 87
 of 'functionCreationDate' element, 91
 of 'modificationRecord' element, 108
 of 'reference' element, 113
 date format, 56
 'DAVEfunc' element
 definition, 81
 discussion, 16
 overview, 16, 18
 root element, 16
 DAVE-ML
 additional resources, 11
 extending, 15
 web site, 11
 'dependentVarPts' element
 as child of 'function' element, 40, 90
 definition, 82
 'dependentVarRef' element
 as child of 'function' element, 40, 90
 definition, 83
 'description' element, 30
 as child of 'breakpointDef' element, 68
 as child of 'fileHeader' element, 21, 88
 as child of 'function' element, 39, 90
 as child of 'griddedTableDef' element, 32, 94
 as child of 'modificationRecord' element, 108
 as child of 'provenance' element, 111
 as child of 'reference' element, 113

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 336 of 343 |

DAVE-ML 2


as child of 'staticShot' element, 119
 as child of 'ungriddedTableDef' element, 35, 123
 as child of 'variableDef' element, 25, 127
 definition, 84
 'docID' attribute (deprecated)
 of 'documentRef' element, 85
 'documentRef' element
 as child of 'provenance' element, 111
 definition, 85
 DSTO, 8, 13, 37

E

'effect' attribute
 of 'uncertainty' element, 50, 121
 'email' attribute (deprecated)
 of 'author' element, 64
 'extraDocRef' element
 as child of 'modificationRecord' element, 108
 definition, 86
 'extrapolate' attribute
 of 'independentVarPts' element, 96
 of 'independentVarRef' element, 98
 overview, 46

F

'fileCreationDate' element (deprecated)
 as child of 'fileHeader' element, 88
 definition, 87
 'fileHeader' element
 as child of 'DAVEfunc' element, 19, 81
 definition, 88
 example of, 22
 introduction, 16
 overview, 21
 'fileVersion' element
 as child of 'fileHeader' element, 21, 88
 definition, 89
 'function' element
 as child of 'DAVEfunc' element, 20, 81
 definition, 90
 example of, 41
 example of simple, 42
 example of with internal table, 41
 introduction, 17
 overview, 38
 with an internal table, 20
 'functionCreationDate' element (deprecated)
 as child of 'provenance' element, 111
 definition, 91

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 337 of 343 |

DAVE-ML 2

'functionDefn' element
 as child of 'function' element, 40, 90
 definition, 92
function table
 dimensionality, 17
 reuse, 17
Furtek, Jeremy, 130
future plans, 58

G


GeneSim, 14
Grant, Peter, 130
'griddedTable' element (deprecated)
 as child of 'functionDefn' element, 92
 definition, 93
 deprecation, 10
'griddedTableDef' element
 as child of 'DAVEfunc' element, 20, 81
 as child of 'functionDefn' element, 92
 definition, 94
 example of, 33
 introduction, 17
 overview, 20, 31
 reuse, 20
'griddedTableRef' element
 as child of 'function' element, 40
 as child of 'functionDefn' element, 92
 definition, 95
'gtID' attribute
 of 'griddedTableDef' element, 32, 94
 of 'griddedTableRef' element, 95

H

HDF5, 13
Hill, Melissa, 5, 130

I

ID strings, 57
'independentVarPts' element
 as child of 'function' element, 39, 90
 definition, 96
'independentVarRef' element
 as child of 'function' element, 40, 90
 definition, 98
'initialValue' attribute
 of 'variableDef' element, 25, 126
'internalValues' element
 as child of 'staticShot' element, 119
 definition, 100

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 338 of 343 |

DAVE-ML 2

'interpolate' attribute
 of 'independentVarPts' element, 96
 of 'independentVarRef' element, 98
 overview, 46
interpolation
 of ungridded data, 20
'isControl' element
 as child of 'variableDef' element, 25, 127
 definition, 101
'isDisturbance' element
 as child of 'variableDef' element, 25, 127
 definition, 102
'isInput' element
 as child of 'variableDef' element, 25, 127
 definition, 103
'isOutput' element
 as child of 'variableDef' element, 25, 127
 definition, 104
'isState' element
 as child of 'variableDef' element, 26, 127
 definition, 105
'isStateDeriv' element
 as child of 'variableDef' element, 26, 127
 definition, 106
'isStdATAA' element
 as child of 'variableDef' element, 26, 127
 definition, 107

K


Keating, Hilary, 130

L

Linse, Dennis, 5, 5, 5, 6, 6, 6, 6, 7, 7, 7, 7, 7, 130

M

'math' element
 as child of 'calculation' element, 70
MathML-2, 15
'max' attribute
 of 'independentVarRef' element, 98
McMinn, J. Dana, 130
'min' attribute
 of 'independentVarRef' element, 98
'modID' attribute
 of 'dataPoint' element, 79
 of 'modificationRecord' element, 108
 of 'modificationRef' element, 109
'modificationRecord' element
 as child of 'fileHeader' element, 22, 88

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 339 of 343 |

DAVE-ML 2

definition, 108
 'modificationRef' element
 as child of 'provenance' element, 111
 definition, 109
 moment reference center, 56

N


'name' attribute
 of 'author' element, 64
 of 'breakpointDef' element, 30, 68
 of 'dependentVarPts' element, 82
 of 'fileHeader' element, 88
 of 'function' element, 39, 90
 of 'functionDefn' element, 92
 of 'griddedTable' element, 93
 of 'griddedTableDef' element, 32, 94
 of 'independentVarPts' element, 96
 of 'staticShot' element, 119
 of 'ungriddedTable' element, 122
 of 'ungriddedTableDef' element, 34, 123
 of 'variableDef' element, 24, 126
 namespace, XML, 57
 NASA
 Ames Research Center, 13
 Dryden Flight Research Center, 13
 Langley Research Center, 13
 Project Orion, 13
 NASP, 13
 Newman, Daniel M., 4, 5, 6, 6, 6, 7, 7, 7, 130
 'normalPDF' element
 as child of 'uncertainty' element, 50, 121
 definition, 110
 'numSigmas' attribute
 of 'normalPDF' element, 110

O

'org' attribute
 of 'author' element, 64

P

points, ordering of, 56
 'provenance' element
 as child of 'checkData' element, 71
 as child of 'fileHeader' element, 22, 88
 as child of 'function' element, 39, 90
 as child of 'griddedTableDef' element, 32, 94
 as child of 'staticShot' element, 119
 as child of 'ungriddedTableDef' element, 35, 123
 as child of 'variableDef' element, 25, 127

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 340 of 343 |

DAVE-ML 2


definition, 111
'provenanceRef' element
as child of 'checkData' element, 71
as child of 'function' element, 90
as child of 'griddedTableDef' element, 94
as child of 'staticShot' element, 119
as child of 'ungriddedTableDef' element, 123
as child of 'variableDef' element, 127
definition, 112
'provID' attribute
of 'provenance' element, 111
of 'provenanceRef' element, 112

R

Rainey, Riley, 130
'reference' element
as child of 'fileHeader' element, 21, 88
definition, 113
'refID' attribute
of 'documentRef' element, 85
of 'extraDocRef' element, 86
of 'modificationRecord' element, 108
of 'reference' element, 113
of 'staticShot' element, 119

S

Schilling, Larry, 13
'sign' attribute
of 'dependentVarPts' element, 82
of 'independentVarPts' element, 96
of 'variableDef' element, 24, 126
'signal' element
as child of 'checkInputs' element, 72
as child of 'checkOutputs' element, 73
as child of 'internalValues' element, 100
definition, 114
'signalID' element
as child of 'signal' element, 114
definition, 115
deprecation, 6
'signalName' element
as child of 'signal' element, 114
definition, 116
signals, 16
'signalUnits' element
as child of 'signal' element, 114
definition, 117
'signalValue' element
as child of 'signal' element, 114

| | | | |
|---|---|---|--------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP- 09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 341 of 343 |

DAVE-ML 2


definition, 118
 sign convention, 56
 'staticShot' element
 as child of 'checkData' element, 43, 71
 definition, 119
 introduction, 17
 statistics
 encoding for, 49
 subsystems, 56
 'symbol' attribute
 of 'variableDef' element, 24, 126

T

'title' attribute
 of 'reference' element, 113
 'tol' element
 as child of 'signal' element, 114
 definition, 120
 TSONT, 13

U

'uncertainty' element
 as child of 'griddedTableDef' element, 32, 94
 as child of 'ungriddedTableDef' element, 35, 123
 as child of 'variableDef' element, 26, 127
 definition, 121
 discussion, 49
 example of
 additive, 52
 normal distribution, 53
 percentage, 51
 with absolute bounds, 51
 with correlation, 54
 'ungriddedTable' element (deprecated)
 as child of 'functionDefn' element, 92
 definition, 122
 deprecation, 10
 'ungriddedTableDef' element
 as child of 'DAVEfunc' element, 20, 81
 as child of 'functionDefn' element, 92
 definition, 123
 example of, 35, 36
 introduction, 17
 overview, 20, 34
 reuse, 20
 'ungriddedTableRef' element
 as child of 'function' element, 40
 as child of 'functionDefn' element, 92
 definition, 124

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 342 of 343 |

DAVE-ML 2


'uniformPDF' element
 as child of 'uncertainty' element, 50, 121
 definition, 125
'units' attribute
 of 'breakpointDef' element, 30, 68
 of 'dependentVarPts' element, 82
 of 'griddedTableDef' element, 32, 94
 of 'independentVarPts' element, 96
 of 'ungriddedTableDef' element, 34, 123
 of 'variableDef' element, 24, 126
units-of-measure, 57
'utID' attribute
 of 'ungriddedTableDef' element, 34, 123
 of 'ungriddedTableRef' element, 124

V

'value' attribute
 of 'confidenceBound' element, 74
'variableDef' element
 as child of 'bounds' element, 65
 as child of 'DAVEfunc' element, 19, 81
 definition, 126
 example of, 26
 example of a local, 27
 example of calculated, 27, 28
 example with extension to MathML-2, 29
 introduction, 16
 order of appearance, 19
 overview, 23
variable definitions, 16
'variableRef' element
 as child of 'bounds' element, 65
 definition, 128
'varID' attribute
 as child of 'signal' element, 114
 definition, 129
 of 'correlatesWith' element, 76
 of 'correlation' element, 77
 of 'dependentVarPts' element, 82
 of 'dependentVarRef' element, 83
 of 'independentVarPts' element, 96
 of 'independentVarRef' element, 98
 of 'variableDef' element, 24, 126
 of 'variableRef' element, 128

X

'xlink:href' attribute
 of 'reference' element, 113
'xlink:type' attribute

| | | | |
|---|---|--|------------------------|
|  | NASA Engineering and Safety Center Technical Assessment Report | Document #: NESC-RP-09-00598 | Version: 1.0 |
| Title: Flight Simulation Model Exchange | | | Page #: 343 of 343 |

DAVE-ML 2

- of 'reference' element, 113
- XML, 11
- XML namespace, 57
- 'xmlns' attribute
 - of 'DAVEfunc' element, 81
- 'xmlns:xlink' attribute
 - of 'reference' element, 113
- 'xns' attribute (deprecated)
 - deprecation, 9
 - of 'author' element, 64

Y

York, Brent, 9, 13, 130

Z

Zimmerman, Curtis, 5, 130

| REPORT DOCUMENTATION PAGE | | | | | Form Approved OMB No. 0704-0188 | |
|---|-------------|----------------------|-------------------------------|---|---|--|
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p> | | | | | | |
| 1. REPORT DATE (DD-MM-YYYY) | | 2. REPORT TYPE | | 3. DATES COVERED (From - To) | | |
| 01-04 - 2011 | | Technical Memorandum | | November 2009 - February 2011 | | |
| 4. TITLE AND SUBTITLE Flight Simulation Model Exchange Appendices | | | | 5a. CONTRACT NUMBER | | |
| | | | | 5b. GRANT NUMBER | | |
| | | | | 5c. PROGRAM ELEMENT NUMBER | | |
| 6. AUTHOR(S) Murri, Daniel G.; Jackson, E. Bruce | | | | 5d. PROJECT NUMBER | | |
| | | | | 5e. TASK NUMBER | | |
| | | | | 5f. WORK UNIT NUMBER 869021.05.07.01.13 | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199 | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER L-20020 NESC-RP-09-00598 | | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001 | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) NASA | | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/TM-2011-217085/Volume II | | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 59 - Mathematical and Computer Sciences Availability: NASA CASI (443) 757-5802 | | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | | |
| 14. ABSTRACT The NASA Engineering and Safety Center Review Board sponsored an assessment of the draft Standard, Flight Dynamics Model Exchange Standard, BSR/ANSI-S-119-201x (S-119) that was conducted by simulation and guidance, navigation, and control engineers from several NASA Centers. The assessment team reviewed the conventions and formats spelled out in the draft Standard and the actual implementation of two example aerodynamic models (a subsonic F-16 and the HL-20 lifting body) encoded in the Extensible Markup Language grammar. During the implementation, the team kept records of lessons learned and provided feedback to the American Institute of Aeronautics and Astronautics Modeling and Simulation Technical Committee representative. This document contains the appendices to the main report. | | | | | | |
| 15. SUBJECT TERMS NASA Engineering and Safety Center; Extensible Markup Language; American Institute of Aeronautics and Astronautics; Modeling and Simulation Technical Committee | | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON | |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | STI Help Desk (email: help@sti.nasa.gov) | |
| U | U | U | UU | 348 | 19b. TELEPHONE NUMBER (Include area code) (443) 757-5802 | |